MIT Technology Review

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Growing Up with Amazon's Alexa

Creating Artificial Sex Cells

David Byrne on Today's Gadgets

Rethinking the Skills Gap



MEET TECH'S RISING STARS

Software engineer Tracy Chou is one of 35 innovators under 35 who are shaping the future of technology. *p40*

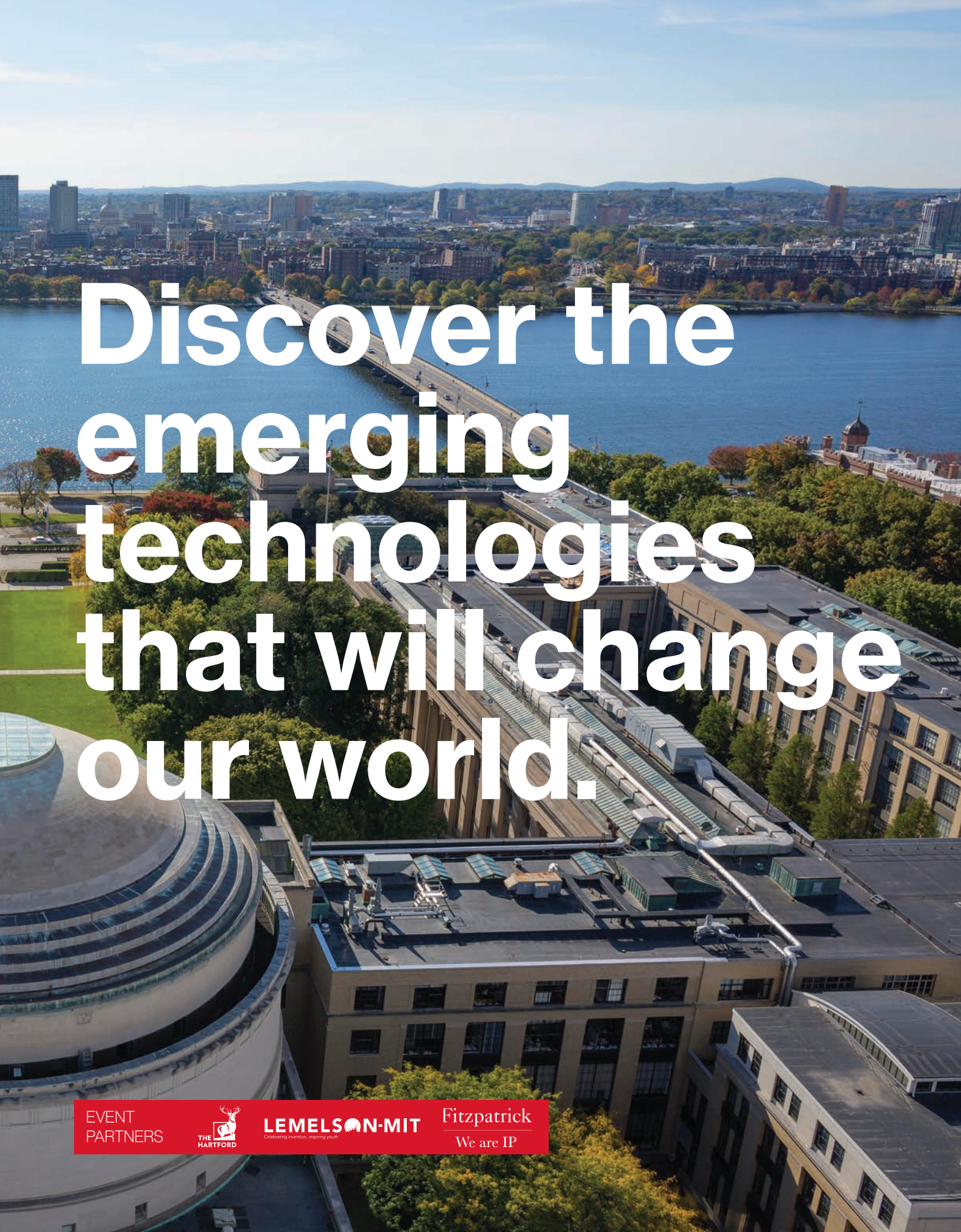
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From the Editor

This Year's 35 Innovators Under the Age of 35



ROXANA PERDUE

David Rotman is editor of **MIT Technology Review.**

You probably won't recognize many, if any, of the remarkable people on this year's list of 35 innovators under the age of 35. But that's likely to change over the next few years as these inventors, entrepreneurs, businesspeople, and scientists revolutionize artificial intelligence, autonomous vehicles, clean energy, and medicine.

Take Ian Goodfellow, a researcher at Google Brain. His breakthrough allows deep neural networks, a type of AI that can learn to recognize patterns in massive amounts of data, to work in tandem to make sense of the world. The neural networks, in effect, teach each other—no need for a human programmer. As Goodfellow puts it, his work is a step toward giving artificial intelligence "a form of imagination." (Stay tuned to see just what type of imagination machines come up with.)

Another rising star in AI is Olga Russakovsky, an assistant professor at Princeton who has made significant contributions in improving the ability of machines to recognize objects. Advances in machine vision are essential if robots are ever to be widely deployed in the home or if self-driving cars are ever to take over the roads, but getting machines to understand what they see is an immensely difficult problem. And, says Russakovsky, "we're not there yet." But like a number of others on our list of young innovators, she's gone beyond technical advances. Recognizing that AI is likely to play an increasingly important role in our lives, Russakovsky believes that the people creating and shaping the technology should represent wider swaths of society. So she started AI4ALL, a nonprofit to increase diversity in the field. Not only does she want to get more women and people from underrepresented populations working in artificial intelligence, but she also wants people from different academic backgrounds, including medicine and psychology, collaborating to create tomorrow's smart machines.

Beyond the impressive technology advances, the list of 35 young innovators is also filled with compelling human stories. Jianxiong Xiao is CEO of AutoX, a company building far cheaper versions of the hardware that enables autonomous vehicles to navigate safely. Xiao recalls growing up in Chaozhou, China. He was fascinated by the computers he had read about in books, but his family couldn't afford such technology. Xiao nevertheless taught himself to touch-type on a keyboard drawn on a piece of paper. He eventually graduated from MIT with a PhD in computer science.

How influential will these unfamiliar faces turn out to be? Consider our first list of innovators under 35, in 1999: it identified names you'd recognize now, such as Apple's Jonathan Ive and iRobot founder Helen Greiner, and others, such as Jackie Ying and Daniel Schrag, who are now world leaders in nanotechnology and climate science. We think the people on this year's list will similarly change how the world thinks about what technology can do.

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2 **From the Editor**

VIEWS

8 **The Perils of Your Gadget**
David Byrne asks if we're forgetting how to interact.

UPFRONT

13 **Baby Genome Sequencing**
In China, decoding the genomes of healthy newborns.

15 **Ernest Moniz Fires Back**
The former energy secretary sees his legacy under attack.

17 **Tech-Loving Octogenarians**
Retirees discover the joys of the digital assistant.

18 **AI Is Coming for StarCraft**
Elite game players reveal how they'd fight high-level AI bots.

22 **Digital Money for China**
A digital-currency experiment with major ramifications.

24 **For Wind, Bigger Is Better**
Larger turbines are giving fossil fuels a run for their money.

REVIEWS

64 **Is the Middle East the Next Tech Powerhouse?**
Startups tap into a growing local taste for technology.
By Christopher M. Schroeder

70 **Growing Up with Alexa**
Kids now have digital butlers to boss around. Is that good?
By Rachel Metz

76 **The Myth of the Skills Gap**
They say American workers lack tech savvy. They're wrong.
By Andrew Weaver

DEMO

80 **To Feed the World, Improve Photosynthesis**
Scientists have a go at improving on nature.
By Katherine Bourzac

88 **Laser Vision**
See the world as a self-driving car sees it.

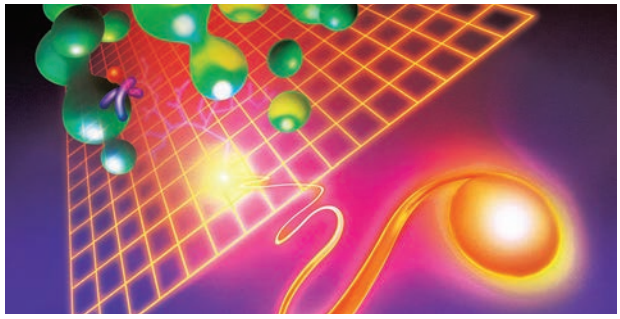
FEATURES

"Alexa, Understand Me" p26



Voice-based assistants aren't just jukeboxes with attitude. They could reshape how we interact with machines. *By George Anders*

A New Way to Reproduce p32



Scientists can now make eggs and sperm out of skin cells. Will it end reproduction as we know it? *By Antonio Regalado*

MOLLY MATALON; ROMAN MURADOV; KEITH RANKIN



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Views

CONNECTIVITY

Eliminating the Human

We are beset by—and immersed in—apps and devices that are quietly reducing the amount of meaningful interaction we have with each other.

I have a theory that much recent tech development and innovation over the last decade or so has an unspoken overarching agenda. It has been about creating the possibility of a world with less human interaction. This tendency is, I suspect, not a bug—it's a feature. We might think Amazon was about making books available to us that we couldn't find locally—and it was, and what a brilliant idea—but maybe it was also just as much about eliminating human contact.

The consumer technology I am talking about doesn't claim or acknowledge that eliminating the need to deal with humans directly is its primary goal, but it is the outcome in a surprising number of cases. I'm sort of thinking maybe it *is* the primary goal, even if it was not aimed at consciously. Judging by the evidence, that conclusion seems inescapable.

This then, is the new norm. Most of the tech news we get barraged with is about algorithms, AI, robots, and self-driving cars, all of which fit this pattern. I am not saying that such developments are not efficient and convenient; this is not a judgment. I am simply noticing a pattern and wondering if, in recognizing that pattern, we might realize that it is only one trajectory of many. There are other possible roads we could be going down, and the one we're on is not inevitable or the only one; it has been (possibly unconsciously) chosen.

I realize I'm making some wild and crazy assumptions and generalizations with this proposal—but I can claim to be, or to have been, in the camp that would identify with the unacknowledged desire to limit human interaction. I grew up happy but also found many social interactions extremely uncomfortable. I often asked myself if there were rules somewhere that I hadn't been told, rules that would explain it all to me. I still sometimes have social niceties "explained" to me. I'm often happy going to a restaurant alone and reading. I wouldn't want to have to do that all the time, but I have no problem with it—though I am sometimes aware of looks that say "Poor man, he has no friends." So I believe I can claim some insight into where this unspoken urge might come from.

Human interaction is often perceived, from an engineer's mind-set, as complicated, inefficient, noisy, and slow. Part of making something "frictionless" is getting the human part out of the way. The point is not that making a world to accommo-



David Byrne

ANDY FRIEDMAN

date this mind-set is bad, but that when one has as much power over the rest of the world as the tech sector does over folks who might not share that worldview, there is the risk of a strange imbalance. The tech world is predominantly male—very much so. Testosterone combined with a drive to eliminate as much interaction with real humans as possible for the sake of "simplicity and efficiency"—do the math, and there's the future.

The evidence

Here are some examples of fairly ubiquitous consumer technologies that allow for less human interaction.

Online ordering and home delivery: Online ordering is hugely convenient. Amazon, FreshDirect, Instacart, etc. have not just cut out interactions at bookstores and checkout lines; they have eliminated *all* human interaction from these transactions, barring the (often paid) online recommendations.

Digital music: Downloads and streaming—there is no physical store, of course, so there are no snobby, know-it-all clerks to deal with. *Whew*, you might say. Some services offer algorithmic recommendations, so you don't even have to discuss music with your friends to know what they like. The service knows what they like, and you can know, too, without actually talking to them. Is the function of music as a kind of social glue and lubricant also being eliminated?

Ride-hailing apps: There is minimal interaction—one doesn't have to tell the driver the address or the preferred route, or interact at all if one doesn't want to.

Driverless cars: In one sense, if you're out with your friends, not having one of you drive means more time to chat. Or drink. Very nice. But driverless tech is also very much aimed at eliminating taxi drivers, truck drivers, delivery drivers, and many others. There are huge advantages to eliminating humans here—theoretically, machines should drive more safely than humans, so there might be fewer accidents and fatalities. The disadvantages include massive job loss. But that's another subject. What I'm seeing here is the consistent "eliminating the human" pattern.

Automated checkout: Eatsa is a new version of the Automat, a once-popular "restaurant" with no visible staff. My local CVS has been training staff to help us learn to use the checkout machines that will replace them. At the same time, they are training their customers to do the work of the cashiers.

Amazon has been testing stores—even grocery stores!—with automated shopping. They're called Amazon Go. The idea is that sensors will know what you've picked up. You can simply walk out with purchases that will be charged to your account, without any human contact.

AI: AI is often (though not always) better at decision-making than humans. In some areas, we might expect this. For example, AI will suggest the fastest route on a map, accounting for traffic and distance, while we as humans would be prone to taking our tried-and-true route. But some less-expected areas where AI is better than humans are also opening up. It is getting better at spotting melanomas than many doctors, for example. Much routine legal work will soon be done by computer programs, and financial assessments are now being done by machines.

Robot workforce: Factories increasingly have fewer and fewer human workers, which means no personalities to deal with, no agitating for overtime, and no illnesses. Using robots avoids an employer's need to think about worker's comp, health care, Social Security, Medicare taxes, and unemployment benefits.

Personal assistants: With improved speech recognition, one can increasingly talk to a machine like Google Home or Amazon Echo rather than a person. Amusing stories abound as the bugs get worked out. A child says, "Alexa, I want a dollhouse" … and lo and behold, the parents find one in their cart.

Big data: Improvements and innovations in crunching massive amounts of data mean that patterns can be recognized in our behavior where they weren't seen previously. Data seems objective, so we tend to trust it, and we may very well come to trust the gleanings from data crunching more than we do ourselves and our human colleagues and friends.

Video games (and virtual reality): Yes, some online games are interactive. But most are played in a room by one person jacked into the game. The interaction is virtual.

Automated high-speed stock buying and selling: A machine crunching huge amounts of data can spot trends and patterns quickly and act on them faster than a person can.

MOOCS: Online education with no direct teacher interaction.

"Social" media: This is social interaction that isn't really social. While Facebook and others frequently claim to offer connection, and do offer the appearance of it, the fact is a lot of social media is a *simulation* of real connection.

What are the effects of less interaction?

Minimizing interaction has some knock-on effects—some of them good, some not. The externalities of efficiency, one might say.

Views

For us as a society, less contact and interaction—real interaction—would seem to lead to less tolerance and understanding of difference, as well as more envy and antagonism. As has been in evidence recently, social media actually increases divisions by amplifying echo effects and allowing us to live in cognitive bubbles. We are fed what we already like or what our similarly inclined friends like (or, more likely now, what someone has paid for us to see in an ad that mimics content). In this way, we actually become less connected—except to those in our group.

Social networks are also a source of unhappiness. A study earlier this year by two social scientists, Holly Shakya at UC San Diego and Nicholas Christakis at Yale, showed that the more people use Facebook, the worse they feel about their lives. While these technologies claim to connect us, then, the surely unintended effect is that they also drive us apart and make us sad and envious.

I'm not saying that many of these tools, apps, and other technologies are not hugely convenient, clever, and efficient. I use many of them myself. But in a sense, they run counter to who we are as human beings.

We have evolved as social creatures, and our ability to cooperate is one of the big factors in our success. I would argue that social interaction and cooperation, the kind that makes us who we are, is something our tools can augment but not replace.

When interaction becomes a strange and unfamiliar thing, then we will have changed who and what we are as a species. Often our rational thinking convinces us that much of our interaction can be reduced to a series of logical decisions—but we are not even aware of many of the layers and subtleties of those interactions. As behavioral economists will tell us, we don't behave rationally, even though we think we do. And Bayesians will tell us that interaction is how we revise our picture of what is going on and what will happen next.

I'd argue there is a danger to democracy as well. Less interaction, even casual interaction, means one can live in a tribal bubble—and we know where that leads.

Is it possible that less human interaction might save us?

Humans are capricious, erratic, emotional, irrational, and biased in what sometimes seem like counterproductive ways. It often seems that our quick-thinking and selfish nature will be our downfall. There are, it would seem, lots of reasons why getting humans out of the equation in many aspects of life might be a good thing.

But I'd argue that while our various irrational tendencies might seem like liabilities, many of those attributes actually work in our favor. Many of our emotional responses have evolved over millennia, and they are based on the probability that they will, more likely than not, offer the best way to deal with a situation.

What are we?

Antonio Damasio, a neuroscientist at UCLA, wrote about a patient he called Elliot, who had damage to his frontal lobe that made him unemotional. In all other respects he was fine—intelligent, healthy—but emotionally he was Spock. Elliot couldn't make decisions. He'd waffle endlessly over details. Damasio concluded that although we think decision-making is rational and machine-like, it's our emotions that enable us to actually decide.

With humans being somewhat unpredictable (well, until an algorithm completely removes that illusion), we get the benefit of surprises, happy accidents, and unexpected connections and intuitions. Interaction, cooperation, and collaboration with others multiplies those opportunities.

We're a social species—we benefit from passing discoveries on, and we benefit from our tendency to cooperate to achieve what we cannot alone. In his book *Sapiens*, Yuval Harari claims this is what allowed us to be so successful. He also claims that this cooperation was often facilitated by an ability to believe in "fictions" such as nations, money, religions, and legal institutions. Machines don't believe in fictions—or not yet, anyway. That's not to say they won't surpass us, but if machines are designed to be mainly self-interested, they may hit a roadblock. And in the meantime, if less human interaction enables us to forget how to cooperate, then we lose our advantage.

I'm not saying that many of these tools, apps, and other technologies are not hugely convenient. But in a sense, they run counter to who we are as human beings.

Our random accidents and odd behaviors are fun—they make life enjoyable. I'm wondering what we're left with when there are fewer and fewer human interactions. Remove humans from the equation, and we are less complete as people and as a society.

"We" do not exist as isolated individuals. We, as individuals, are inhabitants of networks; we are relationships. That is how we prosper and thrive.

David Byrne is a musician and artist who lives in New York City. His most recent book is called How Music Works. *A version of this piece originally appeared on his website, davidbyrne.com.*



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Upfront



MATT PANUSKA

Baby Genome Sequencing for Sale in China

Chinese parents can now decode the genomes of their healthy newborns, revealing disease risks as well as the likelihood of physical traits like male-pattern baldness.

A Boston-based DNA sequencing company is offering to decode the complete genomes of newborns in China, leading some to ask how much parents should know about their children's genes at birth.

Veritas Genetics says the test, ordered by a doctor, will report back on 950 serious early- and later-life disease risks, 200 genes connected to drug reactions, and

Upfront

more than 100 physical traits a child is likely to have.

Called myBabyGenome, the service costs $1,500 and could help identify serious hidden problems in newborns, the company says. But some doctors say the plan is a huge overstep. "I think it's vastly premature to peddle a completely unproven set of data, especially to a vulnerable population like neonates," says Jim Evans, a professor of genetics at the University of North Carolina Chapel Hill.

The problem is that the risk posed by many disease genes remains uncertain. Even if a child has a mutation in a gene, he or she may never be affected, prompting debate among doctors about whether it's useful to inform parents.

The Veritas test also steps into uncharted territory by making predictions about how children will look and act: how wide their nose will be, whether they will overeat or have a "novelty seeking" personality, whether they will have musical ability, and even whether they are likely to go bald decades in the future.

Evans is sharply critical of any effort to predict traits. Especially with psychology, he says, genetic factors aren't well understood. "You run the risk of predestination based on bad science," he says. "Frankly, I think it's a little bit crazy to do genetic tests on your newborn to find out if 40 years from now they are going to be bald."

Veritas, a spinoff of Harvard University's Personal Genome Project, specializes in inexpensive "whole genome" sequencing using the latest speedy DNA technology (see "50 Smartest Companies," July/August 2017). For $999, it has since last year offered adults in the U.S. the chance to learn the sequence of the six billion DNA letters in their cells. A doctor must order that test.

Gene knowledge can be critically useful to anyone who's facing an undiagnosed disease or whose DNA harbors a cancer risk. But for most people the readout is little more than a novelty. Consumer demand for genome scans remains tepid.

Veritas, which already operates a sequencing lab in China, nevertheless appears to be betting that newborn sequencing could become a must-have product for ambitious parents there. In an interview, Mirza Cifric, CEO of Veritas, declined to provide a time line for launching a similar service in the U.S. While a few doctors here have begun sequencing newborns with unexplained illnesses, American medical bodies have opposed sequencing healthy babies because most of the data doesn't lead to clear actions doctors can take. Robert Green, a genetics professor at Harvard University, co-leads a federally funded study called BabySeq that looks at the risks and benefits of sequencing newborns; it has sequenced the genomes of about 100 of them so far. Green reported in October that less than 10 percent of about 2,400 couples offered full-genome sequencing of their children were interested.

The service costs $1,500 and could identify serious hidden problems.

"Some families really don't want anything to do with this. The idea of finding a risk in their beautiful baby of something that might or might not happen is terrifying or repugnant," he says. "But other types of people are information seekers."

In a significant boost for Veritas, Green says he recently agreed to become a paid medical and scientific advisor to the company. He does not believe that the baby sequencing test will be accepted in the U.S. for the time being. But other companies are eyeing more limited DNA tests for babies as a way to expand on the neonatal screening routinely done in hospitals today.

In that process, a doctor pricks a newborn's heel and collects a drop of blood. The sample is then subjected to conventional tests to flag about six to 30 diseases, depending on the county or state, which can all be easily treated if caught early.

One U.S. company, BabyGenes, already offers a DNA panel that tests for about 100 genes and 70 conditions, including many rare ones not included in government tests. "We're trying to get word out there that there is a better way," says the company's laboratory manager, Katie Morris.

By deciphering a baby's entire genome, the Veritas test will go still further. The selection of 950 disease risks it will tell parents about originates with a list assembled by Green's BabySeq project.

But Veritas will not reveal everything, in recognition that not all the information in the genome is appropriate to give parents right away. For instance, it won't tell them about a gene that can strongly predispose people to Alzheimer's in old age. Instead, Veritas says, it will retain the rest of a newborn's genome data and let parents purchase further information at a later date.

That pay-as-you-go business concept was first introduced by a U.S. company called Helix, but it has yet to prove clearly successful. In the U.S., Veritas has received some poor reviews from customers who faced months-long delays in receiving their reports. Cifric says there were delays with some people's orders but that customers are now getting their genomes.

To catch the same high-risk conditions that newborn screening tests do, experts say, the Veritas genome reports will have to be delivered in just a few days.

—Antonio Regalado



BARRY BLITT

Obama's Energy Secretary Addresses Trump's Attacks on His Legacy

MIT's Ernest Moniz has taken on new roles preventing nuclear war, advocating for clean energy, and criticizing Trump's policies.

During nearly four years as U.S. energy secretary, Ernest Moniz earned a reputation as a savvy political hand, particularly as nuclear physicists go, while his Founding Fathers locks made him the most meme-able member of President Barack Obama's cabinet.

When Donald Trump took office, Moniz returned to his academic home at MIT, serving as a professor emeritus and special advisor to President L. Rafael Reif. He held his fire in the early weeks of the new administration, as the White House took aim at Obama's Climate Action Plan, appointed climate-change deniers to critical posts, and sought deep funding cuts to the Department of Energy. But more recently Moniz has returned to the public stage, condemning Trump's withdrawal from the Paris climate agreement.

He also took on a new role as chief executive of the Nuclear Threat Initiative, bringing his experience helping to negotiate the Iran nuclear deal and reviewing the global weapons stockpile to an organization dedicated to preventing attacks with weapons of mass destruction. In addition, he joined the board of fusion startup Tri Alpha Energy and helped establish the Energy Futures Initiative, a nonprofit promoting clean-energy innovation and policies.

In a recent interview with *MIT Technology Review*, Moniz discussed the impact of the administration's policies on U.S. leadership, how it feels to have his legacy come under attack, and what's next for nuclear. Below is an edited excerpt of the interview.

You responded fairly sharply to President Trump's decision to withdraw from the Paris climate deal. What are the biggest or most immediate dangers of that decision in your view?

First of all, withdrawing from the Paris accord fits a pattern of many statements and actions that have called into question

Upfront

our leadership, and frankly our reliability, in terms of carrying out various commitments. The pattern has been to kind of then circle back, and try to mend fences every now and then. But the reality is the uncertainty in our reliability is a very serious issue for our geopolitical leadership.

At the next level, withdrawing from the Paris accord obviously undercuts the leadership on that specific issue, an issue of tremendous global concern. The United States demonstrated leadership in many ways, but in particular in two ways that I'll mention. One was President Obama working with the Chinese to have the joint announcement with President Xi Jinping in November of 2014, which was a sea change on the path to Paris. There was also leadership in the area of clean-energy innovation. The United States Department of Energy was, obviously, in the middle of this, getting 20 countries at that time, plus 28 major international investors, to come forward in Mission Innovation, saying that we need to pick up the pace in innovation to meet our long-term goals.

That leadership and its results were hard-earned, and an announcement to withdraw from the Paris accord obviously weakens that. We will see leadership from the United States now at a sub-national level, with mayors and governors and universities and businesses all stepping forward. I think that is tremendous, and very, very important. But you can't be Pollyannaish about it. There's no way that we aren't compromised when the United States federal government is not exercising leadership.

How do you react to seeing a big part of your and President Obama's climate and clean-energy legacies come under deliberate attack?

The underlying reality is there's virtually no one who believes that [rolling back clean-energy initiatives] is going to lead to a resurgence, let's say, with coal. It's unlikely to lead to new coal plants being built because, again, businesses fully anticipate that in the end we're not going back from a low-carbon trajectory. And any investments in new plants are 40- to 50-year investments, which would have a very good chance of getting stranded a few years down the road.

"The uncertainty in our reliability is a very serious issue for our ... leadership."

But there's no doubt that if the federal government is not rowing in the same direction as the governors and the mayors, etc., it obviously impedes progress and it will just be more costly, and more difficult, for us to get back on track.

You've stressed that nuclear should be a part of the energy mix. So what can or should the U.S. be doing to bolster that sector at this stage?

In a number of states, in one way or another, without calling it exactly that, nuclear is being recognized as a zero-carbon source. And so you've seen states, like New York and Illinois in particular, try to sustain the existing plants because of their low-carbon qualities. Having said that, I do believe we will still see more premature closures. The question is how many, and at what pace. As far as new construction goes, obviously, the cost overruns are tough. I would just say that a direction that I remain very interested in is that of a new generation of small modular reactors. And the first of those is in the licensing process.

NuScale?

NuScale. Right. And that would be aimed for deployment in maybe seven years or so, for a first reactor. I think this is a very interesting direction both because the designs are attractive and, secondly, the financial engineering is very, very different for a 50-megawatt plant versus a 1,200-megawatt plant. Again, I don't want to be Pollyannaish about it, but I think this is a very, very interesting direction, and could present a pathway for new nuclear builds going forward. *—James Temple*

TO MARKET

Mark 1

Voice-Enabled Assistant

COMPANY:
Mycroft

PRICE:
$180

AVAILABILITY:
Now



Mark 1 is no Amazon Echo: it looks like an '80s clock radio mashed up with WALL-E, and speaks with a robotic British accent. But the startup behind it, Mycroft, hopes it has similar appeal to hackers, students, and companies that want a voice-enabled assistant they can run on all kinds of devices and alter at will. Mycroft—whose voice assistant is also called Mycroft—isn't trying to rival digital helpers from Apple, Google, or Amazon, says CEO Joshua Montgomery. It wants to democratize the assistant—making it adaptable for everyone from kids working on school projects to companies that want to use open-source voice-enabled technology for a call center. *—Rachel Metz*

MYCROFT

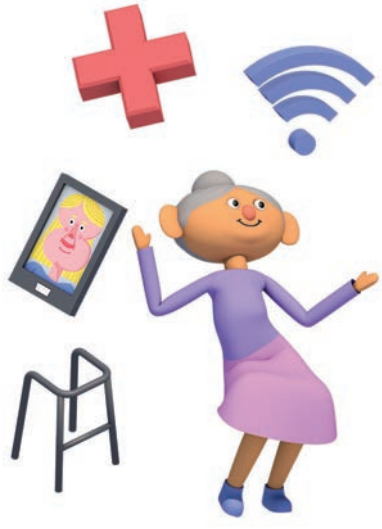
The Octogenarians Who Love Amazon's Alexa

A community of San Diego retirees is using the personal-assistant gadget to listen to audiobooks, keep current with family news, and control home appliances.

When Lois Seed wakes up in the morning, one of the first things she says is "Alexa, what is the weather?" Seed, who is 89 and has vision impaired by macular degeneration, finds it convenient to get weather information by speaking to the Alexa voice-activated assistant on her Amazon Echo. She also asks her Echo to tell her the time and to play classical music from her former hometown radio station.

"Life is more enjoyable [with Alexa]," she says, proving that the recent *Saturday Night Live* spoof about Alexa and seniors couldn't be further from the truth. Seed and about 50 other residents at the Carlsbad by the Sea retirement community near San Diego have been testing the personal-assistant technology inside their homes since late February. Front Porch, the nonprofit organization that runs the community, devised the pilot program after residents expressed interest in Alexa.

Some older adults have been using Alexa on their own to alleviate loneliness and set medication reminders, but Front Porch appears to be the first retirement community to study the technology's impact in depth. And it wants its residents' experiences to help inform how future versions of Alexa might better serve the elderly. The group could represent a sizable new market for Amazon. More than one million Americans reside in assisted-living facilities today, and that number is expected to double by 2030.





Front Porch began by distributing Alexa devices to a small focus group of residents and now hosts biweekly, in-person training workshops, conducts user interviews and in-home visits, and writes research reports. It runs the project through the Front Porch Center for Innovation and Wellbeing, a technology outreach program that is also testing home robots and virtual reality as ways to meet the needs of older adults. The goal is to explore ways to integrate Alexa-enabled devices quickly into its other retirement communities, which have more than 2,000 residents in California.

The majority of the people in the Alexa focus group are in their late 80s. Some use walkers to get around, and some have visual and/or hearing impairments. Most use their Echos in simple ways: to set alarms, stream music, listen to audiobooks, and check the news, sports scores, time, and weather. Jim Bates, a 79-year-old who has hand tremors, finds it far faster and easier to search the Web via Alexa than to type queries on his laptop or iPhone.

Front Porch is also teaching residents how to use Alexa to communicate with family and friends. They can make calls by voice command using Amazon's Alexa-to-Alexa calling service, which is compatible with other Echo devices. If they want to send text messages, they can use an Alexa app called Marvee that translates voice snippets into texts and delivers them to pre-specified contacts. For example, a resident trying to reach her grandson can say, "Alexa, ask Marvee to have Eric call me," and the app will send Eric a text or e-mail that says, "Call Grandma when you get a chance." Family members can also submit their own messages to Marvee, which can be retrieved just by saying, "Alexa, ask Marvee for family news."

There have been frustrations, some surrounding the need to learn how to phrase requests in a way Alexa will understand. So far, the biggest hurdle relates to Alexa's voice. The software speaks with deep bass tones that can sound garbled to people who have hearing impairments. To help those users, Front Porch asked Amazon to release an equalizer feature that would let people adjust Alexa's treble, midrange, and bass range levels. Amazon is reviewing the request, says Davis Park, the Front Porch executive leading the Alexa research project. —*Elizabeth Woyke*

JACK SACHS

Upfront



Professional StarCraft player Byun Hyun Woo playing in the 2016 StarCraft II World Championship Series, which he won.

StarCraft Pros Are Ready to Battle AI

Elite players of the strategy game reveal how they would fight high-level AI bots created by DeepMind, Facebook, and other tech companies.

Message from the world's best StarCraft players to the world's most advanced AI: bring it on.

The space-war computer game is widely regarded as the ultimate challenge for AI programs thanks to its complexity and rapid pace. Expectations for a match-up between a professional StarCraft player and sophisticated AI ratcheted up last year after an AI program beat a highly ranked human player at Go, one of the world's most difficult board games. At the time, a number of AI experts pointed to StarCraft as the next target for an AI-versus-man showdown. Among them: Demis Hassabis, the founder and CEO of DeepMind, the AI-focused division of Alphabet that created the triumphant Go-playing AI program, AlphaGo.

MIT Technology Review asked two leading StarCraft players—Byun Hyun Woo, winner of the 2016 StarCraft II World Championship Series, and Lee Jaedong, a recently retired professional player who now works as a StarCraft commentator—how they would fare against an AlphaGo-type program, the battle strategy they would use, and what rules they would impose to keep the contest fair. Both players live in South Korea, which has long been the world's most competitive StarCraft venue. Both are willing to duel with an elite AI program in a televised StarCraft contest, if one were to be held. But beyond that, their opinions diverge. Byun is far surer about his chances against AI. "I don't think AI can beat [a professional player], at least not in my lifetime," says the 24-year-old.

His confidence stems, in part, from key differences between Go and StarCraft. Go is considered a "perfect-information game" because both players can see the whole board. In StarCraft, players can't view the entire field of play and thus have less information to analyze when planning their moves. That matters because StarCraft is a real-time strategy game

TO MARKET

Workspace

Augmented-Reality Software

COMPANY:
Meta

PRICE:
$949 for Meta 2 headset

AVAILABILITY:
Summer 2017



I've got an embarrassingly large number of Post-it notes dotting my desk, and at any given moment I have too many tabs open on my Web browser. The augmented-reality startup Meta promises I'll manage all of that in midair in the not-so-distant future. Meta's new software, Workspace, lets you view virtual monitors, Web browsers, and sticky notes through the company's augmented-reality headset. It uses a series of shelves with icons as its desktop metaphor; you grab applications from a shelf, move your virtual displays around at will, and scroll virtual Web pages with a finger flick. The goal, says Meta CEO Meron Gribetz, is to replace computer monitors and other gadgets entirely. *—Rachel Metz*

META; PATRICK STRACK FOR BLIZZARD ENTERTAINMENT





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Upfront

that requires players to manage resources, scout and patrol territories, and plan battles. (Players typically win by destroying all of their opponents' structures or forcing them to surrender.) "When you play StarCraft, you have to respond very quickly to lots of uncertainties and variables, but I've noticed that AI like AlphaGo isn't that good at reacting to unexpected scenarios," Byun says. Another reason he is skeptical of StarCraft AI: players need to devise and execute long-term strategies to stay ahead of their opponents, and AI struggles with handling both short- and long-term decision-making.

Lee isn't so sure of his chances. He thinks AI bots could defeat a pro because they never tire and can move much faster than humans. Skill in StarCraft hinges, in part, on how quickly players can tap a keyboard and click a mouse, a metric known as APM ("actions per minute"). Top human players can make several hundred of these commands a minute; AI programs can issue tens of thousands. "Machines will overpower humans if the AI consistently levels up its technology to a point that humans can't follow," says Lee.

StarCraft is a real-time strategy game, which may prove difficult for AI.

Some StarCraft experts believe an AI's APM should be capped at a high human level in a competition. Lee agrees, but Byun thinks that placing any limitations on a bot would diminish the point of pitting the world's best human player against the world's best AI. Instead, he says, he would use "irregular and unconventional playing tactics" to outpace the program. "I would block its attempts to patrol my facilities, to prevent it from monitoring my assets," says Byun. "If my facilities were patrolled, I would drop any building construction plans [and use unexpected scenarios]."

Simple StarCraft AI has been demonstrated at university-hosted competitions over the past few years. The oldest of those contests, AIIDE, which was first held at the University of California, Santa Cruz, in 2010, often makes its winning bot wrangle a skilled amateur. Dave Churchill, an assistant professor of computer science at Memorial University of Newfoundland who has run the AIIDE competition for the past six years, says the contest's AI bots generally play at a "low amateur" level and have never won against a proficient human player.

An AlphaGo-caliber AI program would put up a fiercer fight, though, and there are hints that DeepMind and other tech companies are developing AI programs that can play StarCraft. Last November, DeepMind announced it would collaborate with StarCraft publisher Blizzard to create a free, open-source API tool to enable researchers to test AI algorithms in StarCraft II. Around the same time, Facebook's AI Research group described a reinforcement-learning algorithm it made for StarCraft and released its own free, open-source tools to help AI researchers link deep-learning algorithms to an early version of the game. In March, researchers at Chinese e-commerce giant Alibaba revealed they had written a reinforcement-learning framework for StarCraft. DeepMind declined to comment on any StarCraft AI plans.

When could a future AI bot trounce a professional StarCraft player like Byun or Lee? Churchill estimates within the next five to 10 years, but adds, "If you had asked Go AI experts a month before AlphaGo came out, 'How long before AI can beat the world champion at Go?' most people would have said, 'Five to 10 years.' AI is moving so fast that you never know."

—Elizabeth Woyke and Yoochul Kim

41 YEARS AGO

A Personality of Its Own

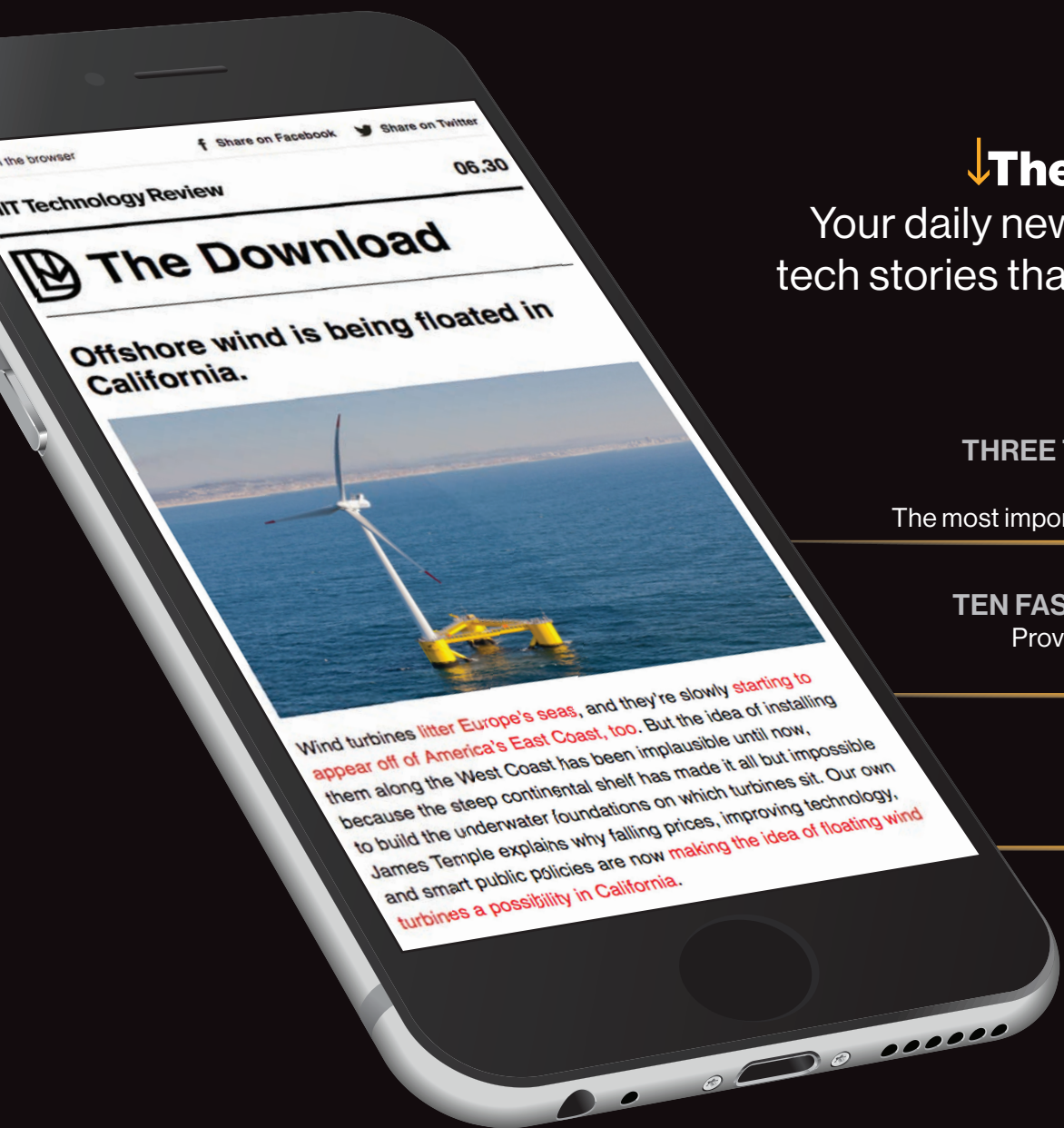


The individual wristwatch telephone through which you can contact anyone, anywhere, will be a mixed blessing which, nevertheless, very few will be able to reject. In fact, we may not have a choice. We may be forced rather quickly to go the whole way, and combine in a single highly portable unit not only communications equipment, but also something like today's pocket-calculators, plus data banks, plus information processing circuits. It would be a constant companion, serving much the same purpose as a human secretary. In a recent novel I called it a "Minisec." In fact, as electronic intelligence develops, it would provide more and more services, finally developing a personality of its own, to a degree which may be unimaginable today.

Excerpted and adapted from "Communications in the Second Century of the Telephone," by science-fiction write Arthur C. Clarke, in the May 1976 issue of Technology Review.

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MIT Technology Review

Upfront

China's Central Bank Has Begun Cautiously Testing a Digital Currency

The People's Bank of China has developed a digital currency that's designed to scale to the number of transactions made every day across the country.

China's central bank is testing a prototype digital currency with mock transactions between it and some of the country's commercial banks.

Speeches and research papers from officials at the People's Bank of China show that the bank's strategy is to introduce the digital currency alongside China's renminbi. But there is currently no timetable for this, and the bank seems to be proceeding cautiously.

Nonetheless the test is a significant step. It shows that China is seriously exploring the technical, logistical, and economic challenges involved in deploying digital money, something that could ultimately have broad implications for its economy and for the global financial system. A digital fiat currency—one backed by the central bank and with the same legal status as a banknote—would lower the cost of financial transactions, thereby helping to make financial services more widely available. This could be especially significant in China, where millions of people still lack access to conventional banks. A digital currency should also be cheaper to manage, and ought to reduce fraud and counterfeiting.

Even more significantly, a digital currency would give the Chinese government greater oversight of digital transactions, which are already booming. And by making transactions more traceable, this could also help reduce corruption, which is a key government priority. Such a currency could even offer real-time economic insights, which would be enormously valuable to policymakers. And finally, it might facilitate cross-border transactions, as well as the use of the renminbi outside of China because the currency would be so easy to obtain.

Digital currencies, also known as cryptocurrencies, have shot to prominence in recent years following a wave of excitement, investment, and speculation focused on Bitcoin, a distributed, cryptographically secured form of money invented by an anonymous individual or group in 2008. Bitcoin's distributed ledger of transactions, known as a blockchain, makes it possible for it to operate without any central authority.

But China is not the only country interested in overhauling its currency. This year India eliminated some banknotes in an effort to reduce tax evasion and illegal income. And while some other central banks, including the Bank of England, the Bank of Canada, Deutsche Bundesbank, and the Monetary Authority of Singapore, are studying digital fiat currencies, China's test appears to be the first of its kind anywhere in the world.

One of the main concerns voiced by other central banks looking at digital fiat currencies is that they could undermine the commercial banking system by making it possible for anyone to have an account with the central bank. China's digital currency is designed to avoid this problem. In a paper published in *Tsinghua Financial Review*,

KEITH RANKIN



an academic journal, and posted online recently, Yao Qian, deputy director of the technology department of the People's Bank of China, wrote that a digital currency could be integrated into the existing banking system, with commercial banks operating digital wallets for the central bank's currency. And while other countries have proposed following Bitcoin's architecture and many of the largest banks in the world are experimenting with it, the currency developed by the People's Bank of China is also different in design. Yao writes that the currency would only use a distributed ledger in a limited way. A blockchain might not be used to process transactions, as this could prove an insurmountable bottleneck for a currency with such a huge transaction volume as the renminbi. But such a distributed ledger might be used to periodically check who owns what. "The ownership of digital currency can be verified directly by the issuing bank, so as to realize peer-to-peer cash transaction[s]," Yao writes. Officials from the People's Bank of China declined to provide any official comment on the development of the digital currency or plans for its use.

There may be good reason to proceed slowly. For all the excitement over digital currencies, Bitcoin is experiencing technical problems as it grows more popular, and the community of developers behind the currency is beset by infighting over its future direction. Bitcoin's value has also oscillated wildly in recent years (as of writing, the value of a bitcoin is $2,757, more than double its value in March). A number of other cryptocurrencies have emerged, and blockchain technology is being explored as a way to track all sorts of different things.

Still, a less decentralized currency under the control of the central bank has significant appeal. "In a place like China, they may see an opportunity to catch up with other countries, to adopt new technology, and maybe even overtake people," says Simon Johnson, a professor at MIT's Sloan School of Management who previously served as the chief economist for the International Monetary Fund. Johnson notes that China is already at the vanguard of experimentation in mobile payments and digital money, which has driven economic growth. "There's a lot of innovation in the private sector with things like Alipay," he says. "And China is also the biggest user of Bitcoin, as far as we can determine."

—Will Knight

QUOTED

"These are pimples on the back of a whale."

— Investor Alex Pasteur on why GlaxoSmithKline decided to sell off its rare-disease unit, which includes a breakthrough gene therapy called Strimvelis.

"I think by the time we are reactive in AI regulation, it's too late."

— Elon Musk, speaking to the National Governors Association about the risks of artificial intelligence if it's left unchecked by regulators.

"I'll be honest with you, I have no clients right now."

— Cathy O'Neil , a mathematician who runs a consultancy to help businesses identify and correct biases in the algorithms they use.

BY THE NUMBERS

20 million

Number of mosquitoes infected with sterilizing bacteria that Alphabet's Verily is releasing in Fresno, California, this year.

$399

Price of an Oculus Rift virtual-reality headset today, which is half what it cost when it hit the market in early 2016.

$535 trillion

Amount it will cost to clean up the atmosphere by 2100, according to a study led by climate researcher James Hansen. That's about seven times the global economy today.

$100,000

Amount that investor Peter Thiel has invested in a project to resurrect the woolly mammoth using genetically modified elephant cells .

3,000

Number of heartbeats after which a 3-D-printed artificial heart developed by Swiss researchers begins to degrade.

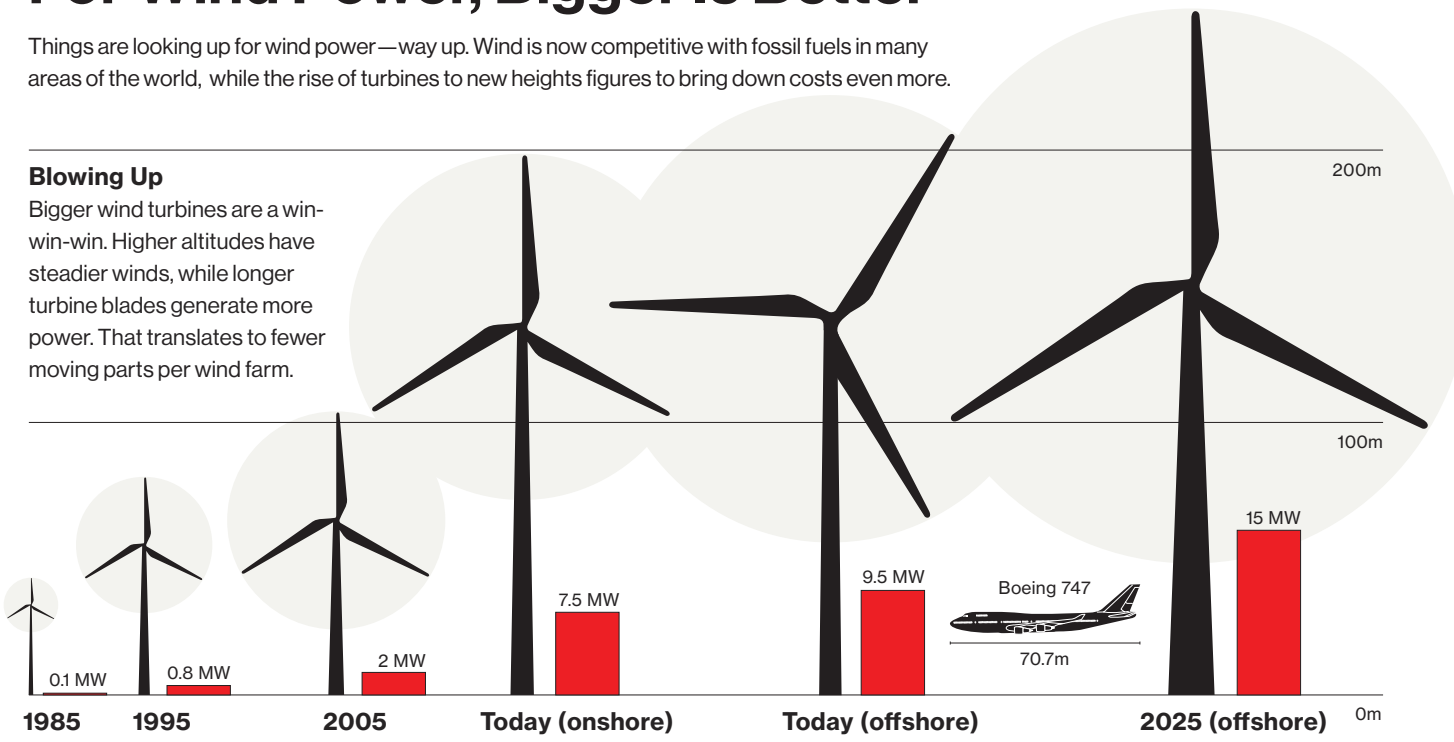
Upfront

For Wind Power, Bigger Is Better

Things are looking up for wind power—way up. Wind is now competitive with fossil fuels in many areas of the world, while the rise of turbines to new heights figures to bring down costs even more.

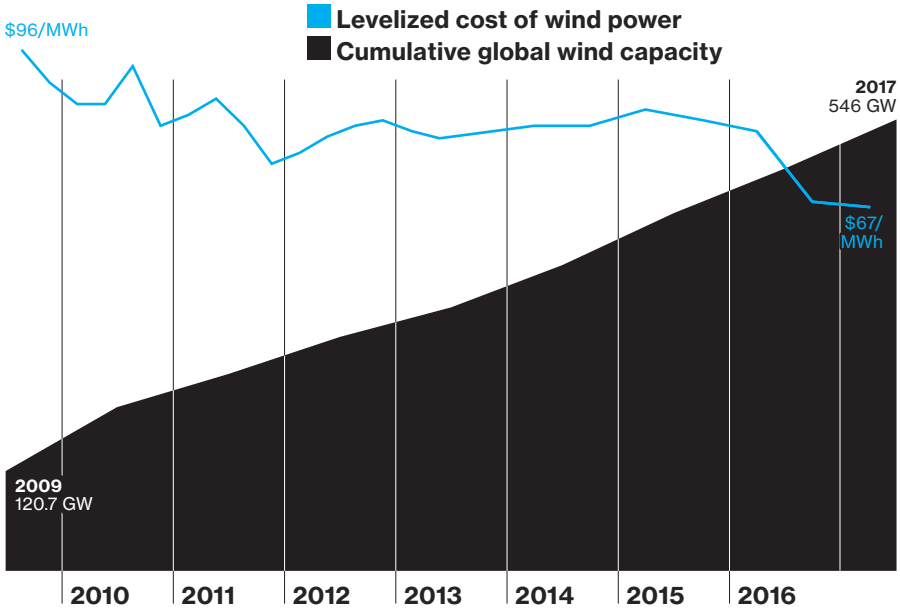
Blowing Up

Bigger wind turbines are a win-win-win. Higher altitudes have steadier winds, while longer turbine blades generate more power. That translates to fewer moving parts per wind farm.



More Turbines for Less

"Levelized cost," measured in megawatt-hours, is the cost of generating electricity without subsidies. Since 2009, it has fallen 30 percent for wind power as capacity has quadrupled.



Cost Competitive

So far in 2017, the levelized cost of wind is on par with that of other sources in key markets.

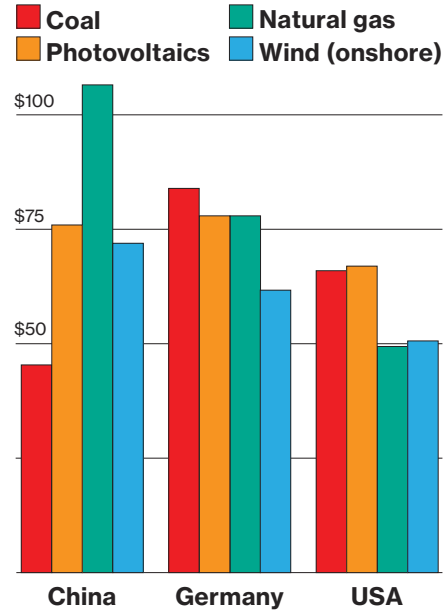


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"Alexa, Understand Me"

Voice-based AI devices aren't just jukeboxes with attitude. They could become the primary way we interact with our machines.

By George Anders
Illustrations by Roman Muradov



On August 31, 2012, four Amazon engineers filed the fundamental patent for what ultimately became Alexa, an artificial-intelligence system designed to engage with one of the world's biggest and most tangled data sets: human speech. The engineers needed just 11 words and a simple diagram to describe how it would work. A male user in a quiet room says: "Please play 'Let It Be,' by the Beatles." A small tabletop machine replies: "No problem, John," and begins playing the requested song.

From that modest start, voice-based AI for the home has become a big business for Amazon and, increasingly, a strategic battleground with its technology rivals. Google, Apple, Samsung, and Microsoft are each putting thousands of researchers and business specialists to work trying to create irresistible versions of easy-to-use devices that we can talk with. "Until now, all of us have bent to accommodate tech, in terms of typing, tapping, or swiping. Now the new user interfaces are bending to us," observes Ahmed Bouzid, the chief executive officer of Witlingo, which builds voice-driven apps of all sorts for banks, universities, law firms, and others.

For Amazon, what started out as a platform for a better jukebox has become something bigger: an artificial-intelligence system built upon, and constantly learning from, human data. Its Alexa-powered Echo cylinder and tinier Dot are omnipresent household helpers that can turn off the lights, tell jokes, or let you read the news hands-free. They also collect reams of data about their users, which is being used to improve Alexa and add to its uses.

Tens of millions of Alexa-powered machines have been sold since their market debut in 2014. In the U.S. market for voice-powered AI devices, Amazon is believed to ring up about 70 percent of all unit sales, though competition is heating up. Google Home has sold millions of units as well, and Apple and Microsoft are launching their own versions soon.

The ultimate payoff is the opportunity to control—or at least influence—three important markets: home automation, home entertainment, and shopping. It's hard to know how many people want to talk to their refrigerators, but patterns of everyday life are changing fast. In the same way that smartphones have changed everything from dating etiquette to pedestrians' walking speed, voice-based AI is beginning to upend many aspects of home life. Why get up to lock the front door or start your car heater on a bitterly cold day, when Alexa or her kin can instantly sort things out instead?

For now, Amazon isn't trying to collect revenue from companies making smart thermostats, lightbulbs, and other Alexa-connected devices. Down the road, though, it's easy to imagine ways that revenue-sharing arrangements or other payments could catch on. The smallest of these three markets, home automation, already accounts for more than $5 billion of spending each year, while retail sales in the U.S. last year totaled $4.9 trillion. Today Amazon makes money on the machines themselves, at prices ranging from $50 for Dots to $230 for the highest-end Echos with video screens, and reaps a second payoff if users end up shopping more heavily at Amazon's vast online store. (Amazon won't disclose those traffic numbers, however.)

For Echos to become as pervasive as smartphones, they will need to do many more things. To that end, Amazon is encouraging independent developers to build new services on the platform, just as Apple has long done with app developers. More than 15,000 such "skills," or apps, have been built so far, and app-building tools have become so easy to snap together that it's now possible to build a simple skill in about an hour, without much programming knowledge. Among the most popular apps are ride-hailing options from Uber and Lyft. Duds include 48 separate skills that bombard listeners with insults.

Among the most ambitious developers are companies making hardware or selling services that work with Alexa. Capital One, for example, is offering Alexa-based bill payment to its banking customers; Toronto-based Ecobee is one of a number of makers of smart thermostats to rig up Alexa-powered versions that let people raise or lower room temperatures merely by uttering a few words. "Our customers have busy lives," says Stuart Lombard, chief executive of Ecobee, which now gets roughly 40 percent of overall sales from its Alexa devices, the 10-year-old company's fastest-growing product line. "They have to fight traffic to get home, and then they have to feed the kids, diaper the baby, and who knows what else. We give them a hands-free way of getting something done while they're in the midst of other tasks."

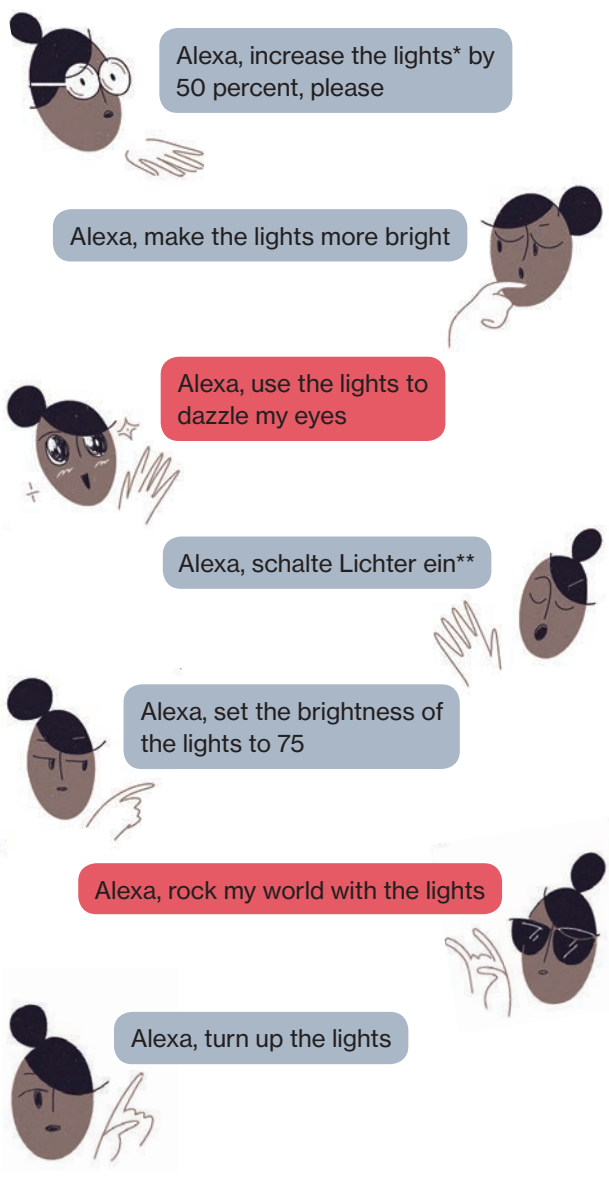
When speech meets AI

What makes voice-based AI so appealing to consumers is its promise to conform to us, to respond to the way we speak—and think—without requiring us to type on a keyboard or screen. That's also what makes it so technically difficult to build. We aren't at all orderly when we talk. Instead, we interrupt ourselves. We let thoughts dangle. We use words, nods, and grunts in odd ways, and we assume that we're making sense even when we aren't.

Thousands of Amazon staffers are working on this challenge, including some at research hubs in Seattle, Sunnyvale, California, and Cambridge, Massachusetts. Even so, Amazon's careers page recently offered 1,100 more Alexa jobs spread

Rules of Engagement

Alexa understands an increasing list of commands. Here are some of the dozen ways you can tell her to make a room brighter (gray), and a few that won't work (red).



* Alexa works with more than 50 smart lighting systems, among them Philips Hue, GE Link Bulb, and Ikea Trådfri.
** A German-language version of Alexa made its debut in 2016. Other non-English versions are expected to follow.

across a dozen departments, including 215 slots for machine-learning specialists. During a meeting at the company's Cambridge offices, I asked Alexa's head scientist, Rohit Prasad, why he needs so many people—and when his research team might be fully built out.

"I'm laughing at every aspect of your question," Prasad replied.

After a few seconds, having regained his composure, Prasad explained that he's been working on speech technology for 20 years, with frustratingly slow results for most of that period. In the past five years, however, giant opportunities have opened up. Creating a really effective voice-triggered AI is a complex and still unconquered task (see "AI's Language Problem," September/October 2016). But while in the past, speech scientists struggled to determine the exact meaning of sometimes-chaotic utterances on the first try, new approaches to machine learning are making progress by taking a different tack: they work from imperfect matches at the outset, followed by rapid fine-tuning of provisional guesses. The key is working through large swaths of user data and learning from earlier mistakes. The more time Alexa spends with its users, the more data it collects to learn from, and the smarter it gets. With progress comes more opportunity, and the need for more manpower.

"Let me give you an example," Prasad said. "If you ask Alexa 'What was Adele's first album?' the answer should be '*19*.' If you then say, 'Play it,' Alexa will know enough to start playing that album." But what if there's some conversational banter in the middle? What if you first ask Alexa what year the album came out, and how many copies it sold? Finish such an exchange with the cryptic "Play it," and earlier versions of Alexa would have been stumped. Now the technology can follow that train of thought, at least sometimes, and recognize that "it" still means "*19*."

This improvement comes from machine-learning techniques that reexamined thousands of previous exchanges in which Alexa stumbled. The system learns what song users actually did want to hear, and where the earlier parts of the conversation first identified that piece of music. "You need to make some assumptions at the beginning about how people will ask for things," says James Glass, head of the spoken-language systems group at MIT. "Then you gather data and tune up your models."

The case for such a machine-learning approach is widely appreciated, Glass says, but making it work requires far more data than university researchers can easily muster. With Alexa's usage surging, Amazon now has access to an expansive repository of human-computer speech interactions—giving it



Some people say “No, no, no”; others prefer “Cancel that,” and a third bunch tries some variant of “Wait, actually, here’s what I want instead.” Alexa doesn’t need to decode each utterance.

the sort of edge in fine-tuning its voice technology that Google has long enjoyed in text-based search queries. Outside data helps, too: a massive database of song lyrics loaded into Alexa in 2016, for example, has helped assure that users asking for the song with “drove my Chevy to the levee” will be steered to Don McLean’s “American Pie.”

One of the newest projects for Prasad’s group highlights the flexibility of this approach. It involves deciphering the moments when users backtrack on their initial requests. Signaling phrases can vary enormously. Some people say “No, no, no”; others prefer “Cancel that,” and a third bunch tries some variant of “Wait, actually, here’s what I want instead.” Alexa doesn’t need to decode each utterance. Large samples and semi-supervised machine learning enable it to outline a cluster of likely markers for negated speech, and then pick up a coherent new request after the change of course.

In addition to making Alexa a better listener, Amazon’s AI experts are using troves of data to make it a better speaker, fine-tuning the cadences of the machine’s synthetic-female voice, in order to boost sustained usage. Traditional attempts at speech synthesis rely on fusing many snippets of recorded human speech. While this technique can produce a reasonably natural sound, it doesn’t lend itself to whispers, irony, or other modulations an engaging human speaker might use. To sharpen Alexa’s handling of everything from feisty dialogue to calm recital, Amazon’s machine-learning algorithms can take a different approach, training on the eager, anxious—and wise-sounding—voices of professional narrators. It helps that Amazon owns the audiobook publisher Audible.

So much to talk about

Among the most ardent adopters of voice-based AI are people who can’t easily type on phones or tablets. Gavin Kerr, chief executive of Philadelphia’s Inglis, which provides housing and services for people with disabilities, has installed Amazon Echo and Dot devices in eight residents’ homes. He hopes to eventually add them to all 300-some residences once pilot testing is complete. “It’s an incredible boon for residents,” Kerr says. “They can be more comfortable. It gives them independence.”

Kerr works with hundreds of people who have multiple sclerosis or other debilitating conditions. For those who are bedridden or use wheelchairs, a hard-to-reach wall thermostat

can be a constant source of torment. "Their bodies have a hard time regulating temperature," Kerr explains. "A room that's 72 °F may feel hot one hour and cold the next." With limited mobility, there's no easy way to get comfortable, especially if round-the-clock assistance isn't available.

With a bit of tinkering, Alexa's software can serve even those with severely restricted speech. Kerr tells of one man in his late 30s who wanted to leave a long-term-care facility and move back into an everyday community. "He told us, 'I'll never be able to use Alexa's commands,'" Kerr recalls. "So we asked him, 'What can you say?' Then we reworked the software so he could make Alexa work on his terms. Now he says 'Mom' when he wants to turn on the kitchen lights, and 'John' when he wants to turn on the bathroom lights."

Although Inglis provides its Echo users with four hours of training, it's far more common for new users to grope their way along. Pull an Echo out of the box, and a bit of packaging will highlight especially common applications, such as playing music, setting alarms, or updating shopping lists. Organized users can call up Alexa control panels on their smartphones or laptops to adjust settings, hunt for new apps, or get guidance on what prompts will make an app work best.

In a widely read blog post in June, Microsoft product manager Darren Austin wrote that Alexa's broader success resides in its ability to alleviate the stresses of an overbooked life. "With the simple action of asking," Austin wrote, "Alexa relieves the negative emotions of uncertainty and the fear of forgetting." Users get hooked on bringing all sorts of momentary puzzlements or desires to Alexa, he contended; it's the companion that's always ready to engage.

Every week—sometimes more often—Alexa general manager Rob Pulciani scans aggregate data on the most common utterances by Alexa and Dot users. Typically, the top of the list is dominated by requests for music, news, weather, traffic, and games. This past spring, however, a newcomer was rising fast. The trending phrase: "Alexa, help me relax."

When users make this request, they are steered into a collection of soothing sounds. Birds chirp; distant waves hit the shore; freight trains rumble through the night. Such ambient-noise loops can keep playing for hours if users choose. Pulciani had regarded these apps as minor oddities when they first appeared on the Alexa platform, in 2015. But they have rapidly picked up a big following. Stressed-out adults use the sounds to fall asleep. Parents turn them into lullaby substitutes for cranky infants. Over the next few weeks after his discovery, Pulciani and colleagues fine-tuned Alexa's internal architecture so new Echo buyers could rapidly discover soothing sounds if they asked for pointers about what new skills to try.



Alexa's broader success resides in its ability to alleviate the stresses of an overbooked life. It's the companion that's always ready to engage.



Sustained conversation

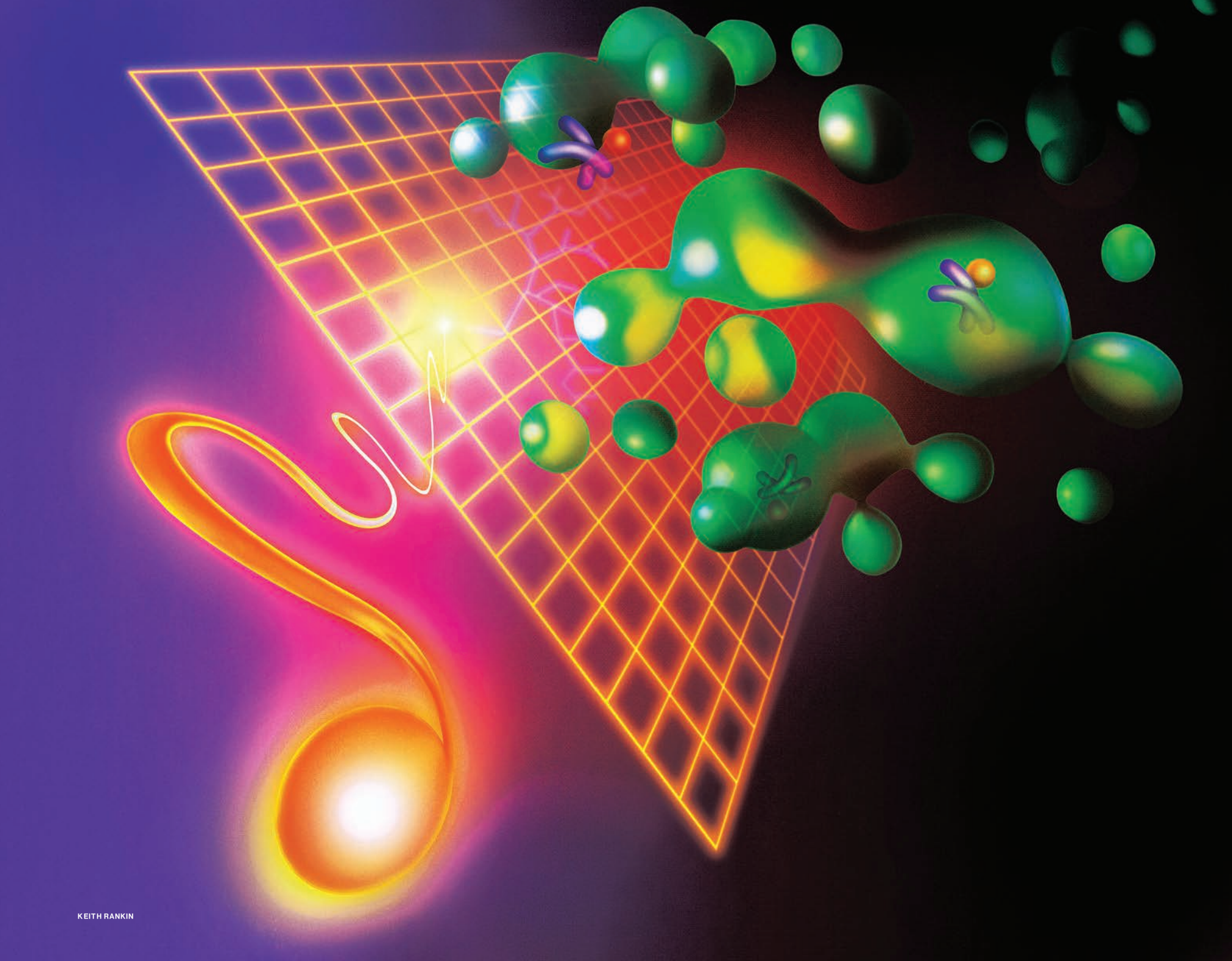
In studies, AI platforms by Google, Apple, Microsoft, and Amazon all show different strengths. Google Assistant is the best on wide-ranging search commands. Apple's Siri and Microsoft's Cortana have other talents. Alexa does particularly well with shopping commands.

The ultimate triumph for voice-based AI would be to carry on a realistic, multi-minute conversation with users. Such a feat will require huge jumps in machines' ability to discern human speakers' intent, even when there isn't an obvious request. Humans can figure out that a friend who says "I haven't been to the gym in weeks" probably wants to talk about stress or self-esteem. For AI software, that's a hard leap. Sudden switches in topic—or oblique allusions—are tough, too.

Eager to strengthen ties with the next generation of AI and speech researchers, a year ago Amazon invited engineering students at a dozen universities worldwide to build voice bots that can sustain a 20-minute conversation. The campus making the most progress by this November's deadline will win a $500,000 prize. I auditioned a half-dozen of these bots one weekend, moving each time from simple queries to trickier open-ended statements of opinion that invited all kinds of possible replies. We got off to a good start when one bot asked me, "Did you see any recent movies?" "Yes," I replied, "we saw *Hidden Figures*." Rather than mimic newspaper reviews of this poignant film about NASA's early years, the social bot shot back: "I thought *Hidden Figures* was very thin on the actual mathematics of it all." Not my take on the film, but it seemed like a charmingly appropriate thing for an AI program to say. Our conversation stalled out soon afterward, but at least we had that brief, beautiful moment.

Alas, none of the other bots could come close. The most confused one blurted out sentences such as "Do you like curb service?" when I thought we were trying to talk about Internet sites. I said something perhaps a little sharp about the bot's limitations, only to be asked: "Can you collective bargaining?" A few days later, when I asked Amazon's Prasad for his take on the social bots, none of their early failings bothered him. "It's a super-important area," he told me. "It's where Alexa could go in terms of being very smart. But this is way harder than playing games like Go or chess. With those games, even though they have a lot of possible moves, you know what the end goal is. With a conversation, you don't even know what the other person is trying to accomplish." When Alexa is able to figure that out, we will really be talking.

George Anders has covered Amazon for national publications since the late 1990s. His newest book is You Can Do Anything.



KEITH RANKIN

A NEW WAY TO REPRODUCE

SCIENTISTS ARE TRYING TO MANUFACTURE EGGS AND SPERM IN THE LABORATORY.

WILL IT END REPRODUCTION AS WE KNOW IT?

By Antonio Regalado

Let's call him B.D., because that's what his wife does on her infertility blog, Shooting Blanks. Several years ago, the 36-year-old learned he was azoospermatic. It means his body makes no sperm at all.

During a recent phone interview, I could hear his wife in the background. She is 35 and facing what she describes as a terrifying countdown toward a life with no children. "Being childless can't be my destiny, it just can't be," she wrote on her blog.

So far, B.D.'s case of infertility has proved untreatable, despite years of pills, vitamins, and a major surgery. But he may still have a long-shot chance at being a father. In 2012, B.D. traveled to Stanford University, where a technician performed a skin punch, removing a small disk of tissue from his shoulder. With a technique called "reprogramming," his skin cells were converted into stem cells that have the potential to mature into various types of human cells. These were then transplanted into the testicles of a mouse. Would the stem cells take cues from their environment and form sperm? Two years later, when the scientists announced what they had found—evidence of primitive human reproductive cells—the provocative findings made the national news.

"I heard it on NPR. I was thinking, 'Son of a bitch—that is me they are talking about,'" B.D. recalls.

The experiment was an attempt to turn ordinary cells obtained from human adults into fully functional gametes—that is, sperm or egg cells. No one has done it yet, but scientists say they are on the cusp of proving it is possible. If they can develop a technology for manufacturing eggs and sperm in the lab, it could bring an end to the problem of infertility for many. But it would also present a fundamental and, to some, troubling advance toward reducing the creation of life to a procedure in a laboratory.

It's part of an explosion of research into how cells make decisions about their fate. To be a neuron or a beating heart cell? From the moment an egg is fertilized, a flurry of biochemical signals orchestrate its division, growth, and specialization as a complete new life is formed. The ambition of biologists who study development is to understand each step and, if they can, copy it in their laboratories.

And no type of cell made in the laboratory would have a bigger scientific and social impact than a sperm or an egg. Recreating these would give scientists access to the chamber of secrets where the links between the generations are forged. "Is there anything more interesting than that? It's so amazing," says Renee Reijo Pera, the scientist who carried out the experiment with B.D.'s cells. "I know people who study how did life begin on Earth, or work on finding the edges of the universe. And I think none of that beats the fact that the sperm and the egg come together and you get a human. And mostly we get two arms and two legs. It is amazingly accurate."

Progress toward making "artificial gametes" has been accelerating. In Japan, mice were born from eggs scientists had manufactured in a dish from a tail cell. Chinese scientists later claimed they had determined the exact sequence of molecular signals required to make mouse sperm. So far, the exact biochemical formula for prompting a stem cell to mature into functional human eggs or sperm remains out of reach. No human skin cell has been turned into a bona fide human reproductive cell. But many scientists believe it's only a matter of time—maybe only a year or two—before they get the right recipe. Recent advances have been "absolutely clear, and breathtaking" says George Daley, a stem-cell biologist who recently became dean of Harvard's medical school.

As control over the fundamental units of reproduction advances, the work is drawing the attention of entrepreneurs, legal experts, bioethicists, and specialists in in vitro fertilization. Some believe that artificial gametes could be the biggest leap forward since IVF itself was first tried, in 1977. Many millions of people can't reproduce, whether because of cancer, accidents, age, or genetics. "You'd be saying that if you have skin, which you do if you are even alive, then you can have sperm," says B.D.

The technology could carry socially disruptive consequences. Women might have children regardless of age. Just grab some skin and poof, young eggs. And if eggs and sperm can be produced in the lab, why not also make embryos by the dozens and test them to pick those with the least disease risk or the best chance of a high IQ? Henry Greely, a member of Stanford University's law faculty and one of the most influential bioethical thinkers in the U.S., finds that scenario likely. Last year, in a book titled *The End of Sex*, he predicted half of couples would stop reproducing naturally by 2040, instead relying on synthetic reproduction using skin or blood as a starting point.

Others say it's possible, even probable, that lab-made gametes could be genetically engineered to remove disease risks. And still more speculative possibilities are on the horizon. For instance, scientists believe it will be possible to make eggs from a man's skin cell and sperm from a woman's skin cell, though the latter would be more difficult because women lack Y chromosomes. This process, termed "sex reversal," in theory could allow reproduction between two people of the same sex. And then there is what Greely terms the "uni-parent—his own sperm, his own egg, his own 'unibaby.'" Such bizarre possibilities have dominated news coverage of recent advances. The episode of *All Things Considered* that B.D. heard on the radio asked whether it would be possible to steal a hair from George Clooney's head and create a clandestine Hollywood sperm bank.

Reijo Pera, now vice president for research at Montana State University, thinks such speculation is misleading and harmful. "I don't view something like in vitro gametogenesis as something scary. I see a group of people that is hurting," she says. She also doubts people will go out of their way to obtain a lab-made baby if they don't need to. "I think that it would grieve people who are infertile to hear those questions," she says. "Because people who can reproduce the natural way—well, that's what they do. I might be naïve, but I think the way to have a healthy child is still two people get together and you have wine and dinner."

REPROGRAMMING CELLS

As a postdoctoral fellow in the 1990s, Reijo Pera helped to identify genes that cause total loss of sperm in men. One no-sperm gene, called *DAZ*, was particularly interesting because it exists only in primates. It means that in addition to our thumbs and our intellect, there are details of human reproduction that are also unique.

The problem for scientists is that many of these details are hidden from view. Scientists are allowed to keep embryos

alive in the lab for only 14 days for research purposes. After that comes a crucial period when a few cells of the developing embryo—about 40—begin a mysterious trek toward what's called the gonadal ridge, the future ovaries or testicles. During that journey, in ways still incompletely understood, the gametes gain the capacity to form a new being.

Reijo Pera has a personal interest in deconstructing how that process works. Early in her career, she was diagnosed with ovarian cancer, a rare kind called a granulosa cell tumor. The disease left her infertile. "People said 'Oh, it's easy to adopt, it's easy to do this, that, or the other.' And I became concerned about a certain coarseness in health care about infertility," she says. She and her husband eventually decided to adopt a child from Guatemala. By 2006, she was learning Spanish and telling *Newsweek*, in an item naming her that year as one of the 20 most influential women in America, that she was going to be a mother. But then Guatemala ceased allowing foreign adoptions. By that time she was 49.

"So we just decided, we'll make a life—me and you and a dog named Boo. And that is what we did," she says.

Despite giving up on motherhood, Reijo Pera did not let the scientific question drop. Instead, she seized on what could be the ultimate answer to infertility.

In 2006, a Japanese scientist named Shinya Yamanaka reported that he'd hit on a formula for turning any adult cell, including skin and blood cells, into what's called an induced pluripotent stem cell. These cells—iPS cells for short—had undergone a kind of molecular amnesia. Just like cells found in newly formed human embryos, they had no fixed identity but were capable of becoming bone, fat, or any other part of the body. The technique proved extraordinarily simple to use. Some compared it the fall of a biological Berlin Wall.

Yamanaka was swiftly handed a Nobel Prize, just six years later. With the development of iPS cells, he had solved an ethical controversy. He'd found a way to explore the earliest stages of human development without using embryos discarded in IVF. What's more, iPS cells came from specific people. That meant the resulting cells would be an exact match to a patient. Scientists began talking about making supplies of "personalized" neurons or heart cells for transplant procedures.

Reijo Pera was among those who understood that genetically identical stem cells could be especially important in reproduction. How else to get a biologically related child from a skin cell? Yet as straightforward as "rewinding" cells with Yamanaka's recipe quickly became, causing them to pursue a chosen fate has proved challenging. Scientists still don't know the exact combination of chemicals that prompt a cell to develop into, say, a neuron rather than part of a toenail. Figuring out that recipe—the precise set of ingredients and steps needed to direct a cell's development—has become one of biology's most daunting puzzles.

In June, 3,900 developmental biologists, biotech executives, and doctors converged at Boston's cavernous convention center for the 15th annual meeting of the International Society for Stem Cell Research. Yamanaka was there, trailed by Japanese TV crews. Many of the scientists in attendance work on creating specific cell types. One, Douglas Melton of Harvard University, says he spent more than a decade determining how to turn stem cells into pancreas cells, the kind that respond to insulin, and finally managed it in 2014. He has two children with diabetes and hopes they could be cured with a cell transplant. "We want complete dominion and mastery over cell fate," Melton told the convention crowd.

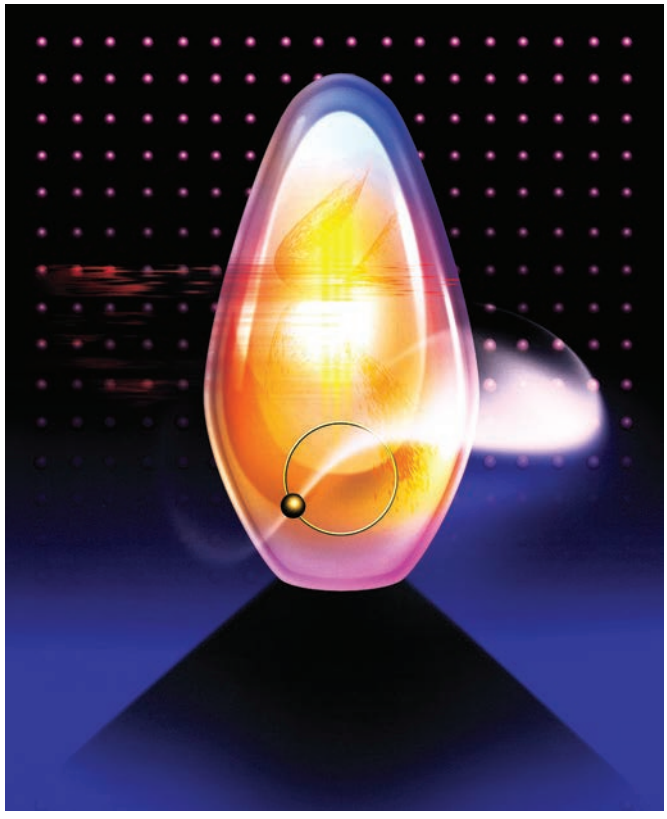
RECIPE FOR LIFE

During the meeting, I tracked down two Japanese scientists, Mitinori Saitou and Katsuhiko Hayashi, who last November reported they had turned mouse tail cells into iPS cells and then into eggs. It was a notable first—the first time in the history of life that artificial eggs had been created outside an animal. Using the synthetic eggs, they'd produced eight mouse pups. Not only had those mice been healthy, but they had gone on to reproduce. The discovery took more than five years to perfect and 17 pages to describe in the journal *Nature*. Yamanaka has called Saitou a "genius."

The two scientists now aim to make human reproductive cells the same way. Saitou told me that Yamanaka himself directed him to try to master the production of human gametes. "He asked me in person. He thought we should do it because it's scientifically very, very interesting," he says. "We are really interested in why these cells can make a new individual. It's the ultimate way of controlling cell fate."

Teams led by Yamanaka have been sweating to prove that iPS cells will have practical applications: creating cures from Japan's Nobel Prize discovery has become a national priority. In 2014, Japanese researchers carried out the first test of iPS-generated cells, for treating blindness. But Saitou says artificial gametes aren't yet on the agenda. "It's not low on the list—it's outside the list. It can't even be compared to replacement cell [therapy]," he says. "I think it's very difficult to use in vitro germ cells to make humans. But not impossible."

It's not just technically difficult: Saitou is nervous about the ethical implications. He's been deluged with letters from infertile couples. Yet in Japan, research guidelines currently forbid scientists from trying to use such cells to build an embryo. The country's cabinet is weighing whether to loosen the rules.



"I don't view something like in vitro gametogenesis as something scary. I see a group of people that is hurting."

The technical obstacles will probably be overcome before the legal ones. That's because, Saitou's misgivings notwithstanding, there is now a race on to perfect a laboratory method for making human eggs. Saitou admitted he's now in a "not so enjoyable" competition with his old mentor, Azim Surani of the University of Cambridge, to be the first to work out the recipe. Hayashi, his former student, now at the University of Kyushu, is also in the race. If any of them do perfect it, other researchers might not be so hesitant to use it in an IVF clinic.

When I asked Hayashi, the younger of the two Japanese scientists, how long it would take to master making human gametes, he said 10 or 20 years. "How soon is the most difficult question, because I am doing the experiments and they are not easy. I don't want to be a liar and say five years," he says. "Five years later someone might blame me."

Scientists can already coax iPS cells to form primitive reproductive cells, like those made from B.D.'s tissue inside a mouse. What's still unsolved is how to take the final step of turning those cells into functional sperm or eggs. In humans, that process isn't fully completed until puberty. With their mice, Saitou and Hayashi tricked the iPS cells by placing them inside a simulated ovary that they constructed out of tissue harvested from fetal mice. Crafting such an incubator out of human fetal cells isn't practical because they are hard to obtain. Instead, Saitou believes, he will need to manufacture the supporting tissue from iPS cells as well. That additional challenge could delay conclusion of the experiment.

If they do make human eggs or sperm, scientists would hit another roadblock. That is because the only way to prove these cells are the real thing would be to create a human offspring. Right now, that's a step the Japanese scientists aren't willing or ready to consider.

Instead, to demonstrate this final step, Hayashi and Saitou are also working with monkeys. Closely related to humans, the animals will be a good model for demonstrating whether their technology "is safe in a primate," according to Hayashi. "What we need to prove is that we can make nice, good-quality eggs. For that we need to demonstrate offspring," he says.

EMBRYO FARMING

Commercial interest is starting to swirl around the scientists. During my conversation with Hayashi, we were joined by Hardy Kagimoto, the CEO of a Japanese biotech company called Healios that is seeking to turn iPS cells into a treatment for blindness. Kagimoto also hopes to team with Hayashi to explore lab-made human gametes. He said a group of IVF doctors who operate a global network of clinics was interested as well. "A big thing is happening, and soci-

ety isn't aware of it," says Kagimoto. "Don't get me wrong, though—if we do anything, we'll do it with the consensus of society."

Although he has patented his inventions, Hayashi so far hasn't been willing to join a company. He says that last November, Japanese venture capitalists asked him to start one to make human eggs. "I refused. I refused because I can't do it yet. Mainly it's because it's technically difficult," he says. "But it's also too immature to contribute to society." Surveys in Japan show about 30 percent of people accept the idea of children from lab-made gametes. Support is highest for use by couples who have tried IVF and failed.

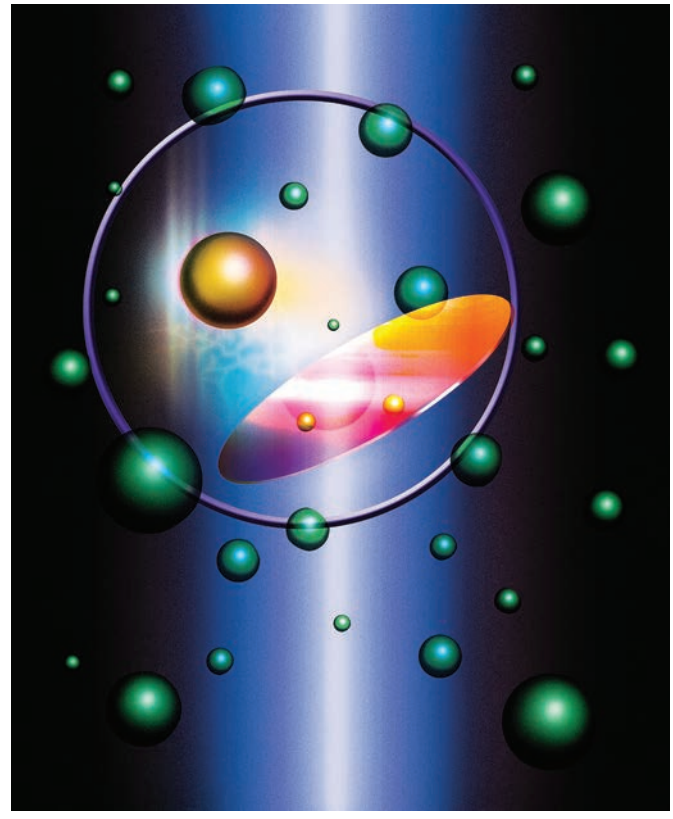
Some investors see far wider possibilities. If eggs could be made from human iPS cells, the supply would potentially be limitless, perhaps leading to what is sometimes called "embryo farming." Kagimoto remarked on one of the images in Hayashi's publications. It is a picture taken through a microscope of dozens of lab-made mouse eggs floating in a drop of water.

In that case, genetic sequencing could be used to inspect each embryo, allowing people to choose the "best" ones—those with desirable genes or without undesirable ones, like those associated with a risk of schizophrenia. This is the scenario predicted by Greely, the legal scholar, who argues that parents would choose artificial reproduction over sexual reproduction if they had enough to gain. "If you have 1,000 eggs, then you can make choices," Kagimoto says.

BRAVE NEW WORLD

During the Boston stem-cell meeting, students strained from the doorways to hear presentations on the ethical issues raised by new reproductive technologies. From the podium, Daley cited Aldous Huxley's 1932 book *Brave New World*, which described a society that controlled reproduction and incubated children in centralized facilities. The picture Huxley drew was dystopian but also "prescient," said Daley. It predicted IVF.

Daley believes scientific advances will allow for scenarios not unlike the one Huxley described. In addition to the Japanese efforts to create gametes, some scientists have created "gastruloids"—self-assembling blobs of cells that look, and behave, much like human embryos. At the same time, researchers are pressing on nature from the other direction. In February, doctors in Philadelphia removed fetal lambs from their mothers and kept each alive until birth inside a transparent fluid-filled sac known as an artificial uterus. The combination of these technologies points to a day when the entire reproduction process, from conception to birth, can



"One only has to speculate how long it is going to be before we can gestate animals entirely ectogenetically, entirely ex utero. So the question then becomes: Can you draw the line?"

be done in the lab. "One only has to speculate how long it is going to be before we can gestate animals entirely ectogenetically, entirely ex utero," Daley said. "So the question then becomes: Can you draw the line?"

Daley has paid particular attention to progress toward turning iPS cells into eggs and sperm, which he terms "a disruptive technology." One reason is that he thinks artificial gametes are likely to be combined with the gene-editing technology called CRISPR, which since it was developed four years ago has made it much easier to alter DNA inside a living cell.

That links artificial gametes to the debate over designer children—what's called "germ-line genetic modification." The debate over that question was rekindled in 2015 after Chinese scientists reported they'd used CRISPR on an embryo in a lab dish to try to remove a gene that causes the blood disease beta thalassemia. The report was initially met with grave concern, in part because CRISPR is not error-free: the experiments suggested that embryos might be imperfectly edited, creating unknown and intolerable risks for any child born this way.

While some critics say modifying the gene pool is a bright ethical line that should never be crossed, that has not been the view of the scientific community (see "Engineering the Perfect Baby," May/June 2015). A report from the National Academy of Sciences, issued this year, concluded that editing human embryos would be permissible if the technique were used to eliminate serious diseases such as Huntington's, a fatal brain disorder. While the committee did oppose using genetic engineering for mere enhancements—blue eyes and intelligence, say—the report left the definition of a disease open to interpretation.

The reason the report paid special attention to artificial gametes is that editing might be carried out with great precision in iPS cells. Once the perfect iPS cells were in hand, they could be induced to create gametes with the specified genetic improvement.

The idea of using CRISPR in stem cells has already been successfully implemented in mice. In China, a scientist named Jinsong Li edited mouse stem cells and removed a gene that causes cataracts. When he generated sperm and later fertilized eggs, the resulting animals appeared to have been edited with "100 percent efficiency." Such reports give scientists reason to think the best argument against germ-line modification—that it will never be reliable or safe enough—is quickly evaporating. "It's no longer possible to say it will not be feasible," says Richard Hynes, an MIT professor who is one of the two senior authors of the National Academy report.

HUGE DEMAND

At the Harvard Stem Cell Institute, an IVF doctor and scientist named Werner Neuhausser is among those exploring how genome sequencing, stem cells, and genome editing could all come together to change reproduction. Neuhausser spends one day a week at Boston IVF, a large fertility center where he meets with patients. The other four days a week he has spent verifying and trying to extend the discoveries being made in Japan and elsewhere.

As an IVF doctor, Neuhausser told me, he would "absolutely" see demand for lab-made sperm and especially lab-made eggs. "This is a big deal if it becomes possible," he says.

Like Kagimoto, Neuhausser believes it's likely that embryos will be measured and their attributes quantified: "We are going to end up for each embryo that it has this risk of heart disease and that risk of psychiatric disease compared to the general population, and then how do you choose?" Neuhausser thinks parents may not have to. Instead, he says, parents could opt to genetically improve their own reproductive cells. "You could sequence the prospective parents' genomes and then you can ask, 'Are there variants you could correct before you reproduce?' This is something that we haven't thought through. It would depend greatly on the risks, and there is a lot we don't know," he says. "No one wants to use this in a patient anytime soon."

Gene editing of gametes is already being explored in his Harvard University lab. The team is obtaining sperm from men who carry a gene that causes amyotrophic lateral sclerosis, or ALS, a devastating neurological disease, and plan to try to remove the mutation using CRISPR. After his lab corrects the error, it will sequence the sperm cells to see the results.

But Neuhausser says the more precise approach would be to make genetic corrections in iPS cells instead. These cells grow and multiply vigorously in the lab. Once they were edited, then eggs or sperm could be created from them. "You would gain access to the genome; you could change the genome at will. It's controversial, of course," he says. "But we should definitely investigate whether it works or not."

The futuristic technology of gametes-in-a-dish can't come soon enough for men like B.D. He told me that he holds out hope he'll be "the first candidate or one of the first" if a treatment using lab-made sperm ever gets approved. But it's not likely to happen in time for him. He says he and his wife recently set a date on which they'd give up trying to have children. It's September 2019.

Antonio Regalado is MIT Technology Review*'s senior editor for biomedicine.*

INNOVATORS INNOVATORS INNOVATORS INNOVATORS

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Quoc Le
Research Scientist, Google

Jennifer Lewis
Wyss Professor of Biomaterials Engineering, Harvard University

Hao Li
CEO, Pinscreen; Assistant Professor of Computer Science, University of Southern California

Mick Mountz
Founder and CEO, Kiva Systems

Carmichael Roberts
Entrepreneur and General Partner, North Bridge Venture Partners

John Rogers
Professor of Chemistry and Materials Science & Engineering, University of Illinois

Umar Saif
Vice Chancellor, ITU Punjab, Pakistan

Rachel Sheinbein
Managing Director, Makeda Capital

Mark Surman
Executive Director, Mozilla Foundation

Kay Tye
Assistant Professor, Picower Institute for Learning and Memory, MIT

Cyrus Wadia
Vice President, Sustainable Business and Innovation, Nike

Jennifer West
Professor of Engineering, Duke University

Jackie Yi-Ru Ying
Executive Director, Institute of Bioengineering and Nanotechnology, Singapore

Feng Zhang
Core Institute Member, Broad Institute, MIT and Harvard

Ben Zhao
Neubauer Professor of Computer Science, University of Chicago

This publication, as a rule, focuses on the technology first—the breakthrough, the surprise, the accidental discovery with the potential to upend the way we live, for good or ill. This issue, our annual look at 35 outstanding innovators under 35, is a reminder that behind all those innovations are people with dreams, fears, and ambitions, tinkering away—sometimes in solitude, sometimes with collaborators. Sometimes they hack away at a problem for years before figuring out a way forward. Sometimes they stumble on a solution they didn't know they were searching for. More than 500 people were nominated for this year's list. From those applications the list was winnowed down to under 100 and sent to a panel of judges (see facing page) with impressive expertise in such areas as venture capital, neuroscience, and materials science. The editors of *MIT Technology Review* then made a final decision, choosing the top 35 innovators.

So who made the list? Here are a few: Katherine Taylor makes water pumps cheap enough to let an Indian farmer access underground water during the dry season. Lorenz Meier, frustrated with the state of the art in drone control, decided to build his own system instead. Svenja Hinderer saw the terrible flaw in artificial heart valves, a life-saving device: they wear out. She's developing a biodegradable version that might, over a period of years, be replaced by a person's own cells.

Innovation isn't limited to the young—far from it. That isn't the point. Instead, we hope these portraits offer a sense of the variety of work being done in technology, an inkling of the new trends, and a sense of what's coming next.

—The Editors

UNDER 35
UNDER 35
UNDER 35
UNDER 35

VISIONARIES



TRACY CHOU

COREY OLSEN

"I had serious questions about whether I was going to stay in tech. And I really thought the problem was me."

Silicon Valley loves data. But until recently, there was one subject where tech companies showed little interest at all in the numbers: the diversity of their workforces. It's not that the statistics were downplayed—the numbers didn't even exist.

Today most big tech companies have issued public reports on diversity, and there's an independent, crowdsourced data repository at GitHub that collects information on tech workforces. And this has happened in no small part because Tracy Chou, a Pinterest software engineer at the time, wrote a post on Medium in the fall of 2013 called simply "Where are the numbers?"

Chou wrote the post after returning from a conference where she heard Facebook COO Sheryl Sandberg say the number of women in tech was dropping. "I didn't think she was wrong," Chou says. "But I also thought: 'How does she know? There are no numbers.' I knew there was this problem."

Chou's Medium post quickly went viral. And soon the numbers began to flow—first via Twitter, and then via that GitHub repository, which Chou set up. Within a few weeks, Chou had data on more than 50 companies (the repository now has numbers for hundreds), and by the summer of 2014, a host of the Valley's most powerful companies had released demographic reports on their workforces. The numbers were dismal—in general, somewhere between 10 and 20 percent of workers in technology positions were women, and one study found that 45 percent of Silicon Valley companies didn't have a single female executive. But at least the data now existed.

As this was happening, Chou continued her coding work at Pinterest, but she also found herself in demand as a speaker and panelist. Last spring, she teamed up with a group of seven other women—including venture capitalist Ellen Pao and Slack engineer Erica Joy Baker—to form Project Include, an organization designed to help CEOs implement diversity and inclusion strategies at their companies.

Chou isn't, and doesn't want to be, a professional activist. "It's fulfilling to work on this issue, and I can have an impact here," she says. "But I see it as a complement to my main work, which is building things and making products." Nonetheless, she's become a voice of authority on tech's diversity problem because she's unusually good at articulating the connections between the personal experience of women in the Valley and the systemic sexism they face, while also identifying how a lack of diversity hurts companies themselves. For instance, there is clearly a pipeline problem when it comes to gender and technology—not enough young women take classes in science, technology, engineering, and math or graduate with STEM degrees. But it's also true, as Chou argues, that the pipeline problem can't explain the high rate of attrition for women in tech, or the lack of women in senior positions. In other words, the pipeline for women gets even more narrow once you're inside a company.

Sometimes that's because of extraordinarily retrograde, garden-variety sexism, exemplified by the recent problems at Uber or the men who regularly told Chou, "You're too pretty to be a coder." It's also because at many companies there's an implicit (and sometimes explicit) assumption that women are less naturally adept at coding, and less willing to work hard.

Chou, for example, went to Stanford for an undergrad degree in electrical engineering and got a master's there in computer science, and had internships at Facebook and Google. Yet at her first job she regularly dealt with casually dismissive sexism, making her question whether she belonged in the industry. "I loved coding," she says. "But I just felt something was off. I felt out of place, and I had serious questions about whether I was going to stay in tech. And I really thought the problem was me."

A large body of research shows that making organizations and teams more diverse also improves their performance. Diversity makes teams less likely to succumb to groupthink and helps companies reach untapped markets. "Products tend to be built to solve the problems of the people building them," Chou says. "And that's not a bad thing, necessarily. But it means that in the Valley lots of energy and attention goes into solving the problems of young urban men with lots of disposable income, and that much less attention goes to solving the problems of women, older people, children, and so on."

Despite the evidence, plenty of companies still need convincing. "There's lots of diversity theater and lip service paid to the concept," Chou says. "And maybe we've helped weed out some of the most egregious actors. But there's a long way to go." *—James Surowiecki*

Greg Brockman

TRYING TO MAKE SURE THAT AI BENEFITS HUMANITY.

Human-like artificial intelligence is still a long way off, but Greg Brockman believes the time to start thinking about its safety is now. That's why, after helping to build the online-payments firm Stripe, he cofounded OpenAI along with Elon Musk and others. The nonprofit research group focuses on making sure AI continues to benefit humanity even as it increases in sophistication. Brockman plays many roles at the firm, from recruiting to helping researchers test new learning algorithms. In the long term, he says, a general AI system will need something akin to a sense of shame to prevent it from misbehaving. "It's going to be the most important technology that humans ever create," he says, "so getting that right seems pretty important." *—Mike Orcutt*





Abdigani Diriye

"Like many Somalis, I fled my homeland because of the civil war. At age five I moved to the U.K. because I had family there. At university I started becoming more aware of the world and realized I was quite fortunate to be where I am. So in 2012 I helped start Innovate Ventures to train and support Somali techies.

"We started with a two-week coding camp in Somalia for about 15 people. In 2016 we partnered with Oxfam and others, and ran a 10-week accelerator for startups. We were hoping to get 40 to 50 applicants, but we ended up getting around 180. For this year's accelerator we've received almost 400 applicants. Somaliland and Somalia face fundamental challenges in health care, education, and agriculture, but innovation, technology, and startups have the potential to fast-track the country's development. We've started to take steps in that direction." *—as told to Elizabeth Woyke*

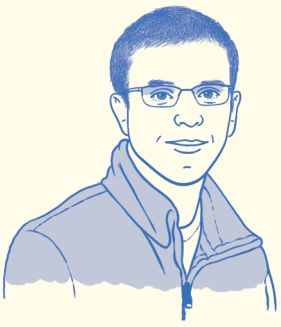
Amanda Randles

PERSONALIZED SIMULATIONS OF BLOOD FLOW IN THE BODY.

Amanda Randles, an assistant professor of biomedical engineering at Duke University, is building software that simulates blood flowing throughout the human body in a model based on medical images of a particular person. The code base is called "HARVEY," after William Harvey, a 17th-century surgeon who first described the circulatory system. The software requires a supercomputer to crunch calculations on the fluid dynamics of millions of blood cells as they move through the blood vessels. Randles has other plans for her fluid-dynamic model of the circulatory system. Next up: scanning newborns with heart problems to guide surgeons and predicting how cancer cells move through the body.

—Antonio Regalado





Viktor Adalsteinsson

In his lab at the Broad Institute in Cambridge, Massachusetts, Viktor Adalsteinsson has put an automated system in place that scans blood samples for traces of tumor DNA—a so-called liquid biopsy. Collecting genetic information on advanced cancers might lead to clues about what drives the disease in later stages and what drugs to give patients. Adalsteinsson, whose mother succumbed to breast cancer while he was earning his PhD, is now looking to improve treatment as part of several projects, including one that sends blood collection tubes to women fighting breast cancer across America. "The doctors and patients cross their fingers and there's a lot of watching and waiting," says Adalsteinsson. "Now we can closely monitor patients' responses to therapy and see what's causing treatments to fail." *—Antonio Regalado*

ILLUSTRATED PORTRAITS BY GRAFILU

GANG WANG



KA XIAOXI

Artificial intelligence has reached "a critical point," says Gang Wang—it's moved beyond the lab and is now ready for mass-market consumer products. Wang, who joined Alibaba's AI lab in March, is at the forefront of the push to make AI practical for consumer products, and he's doing it for one of the world's most ambitious companies in the world's biggest consumer market. He was one of the scientists behind the Tmall Genie, Alibaba's first AI-based product, released in July. Analogous to Amazon's Echo, the device can make purchases on Alibaba's shopping sites and perform other tasks, such as playing music and checking calendars through voice commands.

"The design of neural networks needs to be intertwined with real-world applications," says Wang. "Only in this way can we create a product that's useful in a commercial environment." —*Yiting Sun*

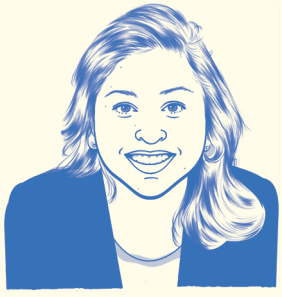

ADRIENNE
PORTER FELT
LEADING THE PUSH FOR A
MORE SECURE INTERNET.
MOLLY MATALON

Anca Dragan

HELPING ROBOTS AND PEOPLE MAKE SENSE OF EACH OTHER.

Anca Dragan, an assistant professor of electrical engineering and computer science at UC Berkeley, is working to distill complicated or vague human behavior into simple mathematical models that robots can understand. She says many conflicts that arise when humans and robots try to work together come from a lack of transparency about each other's intentions. Teaching a robot to understand how it might influence a person's behavior could solve that. One pressing application for this work is in helping self-driving cars and human-driven cars to anticipate each other's next moves. *—Julia Sklar*





Neha Narkhede

"WE VIEW OUR TECHNOLOGY AS A CENTRAL NERVOUS SYSTEM FOR COMPANIES THAT AGGREGATES DATA AND MAKES SENSE OF IT WITHIN MILLISECONDS, AT SCALE."

—Neha Narkhede, co-inventor of Apache Kafka, software for massive data processing in real time. She's also CTO of Confluent, which builds tools to enhance Kafka. *(as told to Elizabeth Woyke)*

The next time you open up Google's Chrome Web browser, take a look at the little green icon that appears in the left corner of the URL bar whenever you're on a secure website. It's a lock, and if it's green it signals that the website you're on is encrypting data as it flows between you and the site. But not everyone knows what it is or what it represents, and that's where Adrienne Porter Felt comes in.

As a software engineer for Chrome, Porter Felt has taken on the task of making the Internet more secure and helping users of the world's most popular browser make smart, informed choices about their safety and privacy while online. This includes heading a years-long push to convince the world's websites, which traditionally used the unencrypted HTTP to send data from one point to another, to switch to the secure version, HTTPS.

Why is it tricky to come up with online security measures that work for all kinds of people?

Part of it is that security measures generally stop people from doing things. The way we keep you safe is by telling you no. But this has very real costs. You can scare people … you can keep people from using the Internet at all. On the other hand, if you don't do anything you put people and their data at very real risk. So you have to figure out how to strike just the right balance. And with multiple billion users it's very difficult to find a balance that makes everyone happy.

One way you are trying to make people safer while they're online is by encouraging websites to use HTTPS. What makes this a complicated process?

Think about a site like the Washington Post. When you go to the Washington Post's home page, there's going to be 100 different [assets from various websites] that are loaded. All of those have to support HTTPS before the Washington Post itself can do it. Sites need to make sure there's no revenue hit, they need to make sure there's no [search] ranking hit, they need to make sure there's no performance hit. And then they can switch. All these things can be done. Sites are transitioning very successfully at scale now. But it is work.

Now that many of the biggest websites have made the switch from HTTP to HTTPS, what are you focusing on?

The long tail is a big problem. There are lots and lots of sites that are out there. Some that are barely maintained, some that are run by your dentist, your hairdresser, a teacher at a local elementary school, and I don't see them rushing to add support for HTTPS. The question is now, "Okay, we've hit all the really popular sites, we're starting to get to the medium sites—what do we do for the rest of the Internet?" I don't want to get in a state where oh, great, you're secure if you go to a big company but not if you go to a small, independent site. Because I still want people to feel like they can go everywhere on the Web. *—Rachel Metz*

JIANXIONG XIAO



MOLLY MATALON

Jianxiong Xiao aims to make self-driving cars as widely accessible as computers are today. He's the founder and CEO of AutoX, which recently demonstrated an autonomous car built not with expensive laser sensors but with ordinary webcams and some sophisticated computer-vision algorithms. Remarkably, the vehicle can navigate even at night and in bad weather.

AutoX hasn't revealed details of its software, but Xiao is an expert at using deep learning, an AI technique that lets machines teach themselves to perform difficult tasks such as recognizing pedestrians from different angles and in different lighting.

Growing up without much money in Chaozhou, a city in eastern China, Xiao became mesmerized by books about computers—fantastic-sounding machines that could encode knowledge, logic, and reason. Without access to the real thing, he taught himself to touch-type on a keyboard drawn on paper.

The soft-spoken entrepreneur, also an assistant professor at Princeton, asks people to call him "Professor X" rather than struggle to pronounce his name. He's published dozens of papers demonstrating clever ways of teaching machines to understand and interact with the world. Last year, Xiao showed how an autonomous car could learn about salient visual features of the real world by contrasting features shown in Google Maps with images from Google Street View.

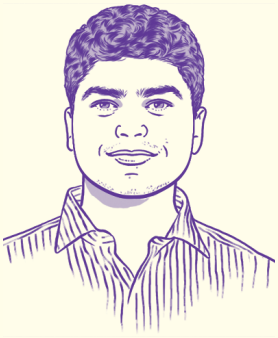
—Will Knight

Rachel Haurwitz

Rachel Haurwitz quickly went from lab rat to CEO at the center of the frenzy over CRISPR, the breakthrough gene-editing technology. In 2012 she'd been working at Jennifer Doudna's lab at the University of California, Berkeley, when it made a breakthrough showing how to edit any DNA strand using CRISPR. Weeks later, Haurwitz traded the lab's top-floor views of San Francisco Bay for a sub-basement office with no cell coverage and one desk. There she became CEO of Caribou Biosciences, a spinout that has licensed Berkeley's CRISPR patents and has made deals with drug makers, research firms, and agricultural giants like DuPont. She now oversees a staff of 44 that spends its time improving the core gene-editing technology. One recent development: a tool called SITE-Seq to help spot when CRISPR makes mistakes.

—Antonio Regalado





Tallis Gomes

AN "UBER FOR BEAUTY."

Tallis Gomes had spent four years as the CEO of EasyTaxi, the "Uber of Brazil," when he decided in 2015 to aim the same concept in a new direction—the beauty industry.

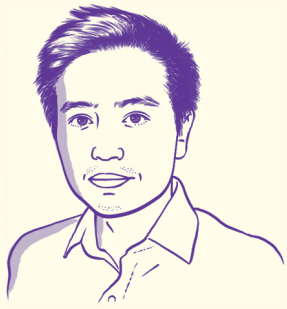
His on-demand services platform, called Singu, allows customers to summon a masseuse, manicurist, or other beauty professional to their home or office. Scheduling is done by an algorithm factoring in data from Singu and third parties, including location and weather. The professionals see fewer customers than they would in a shop, but they make more money because they don't have to cover the overhead. Gomes says the algorithm can get a manicurist as many as 110 customers in a month, and earnings of $2,000—comparable to what a lawyer or junior engineer might make. *—Nanette Byrnes*

Bill Liu

HIS FLEXIBLE COMPONENTS COULD CHANGE THE WAY PEOPLE USE ELECTRONICS.

Bill Liu thinks he can do something Samsung, LG, and Lenovo can't: manufacture affordable, flexible electronics that can be bent, folded, or rolled up into a tube.

Academic researchers have had similar ideas, but Liu moved fast to commercialize his vision. In 2012, he founded a startup called Royole, and in 2014 the company unveiled the world's thinnest flexible display. Compared with rival technologies that can be curved into a fixed shape but aren't completely pliable, Royole's displays are as thin as an onion skin and can be rolled tightly around a pen. *—Elizabeth Woyke*





Kathy Gong

DEVELOPING NEW MODELS FOR ENTREPRENEURSHIP IN CHINA.

Kathy Gong became a chess master at 13, and four years later she boarded a plane with a one-way ticket to New York City to attend Columbia University. She knew little English at the time but learned as she studied, and after graduation she returned to China, where she soon became a standout among a rising class of fearless young technology entrepreneurs. Gong has launched a series of companies in different industries. One is Law.ai, a machine-learning company that created both a robotic divorce lawyer called Lily and a robotic visa and immigration lawyer called Mike. Now Gong and her team have founded a new company called Wafa Games that's aiming to test the Middle East market, which Gong says most other game companies are ignoring.

—Nanette Byrnes

PIONEERS



JENNA WIENS

MEGAN MCISAAC

A sizable percentage of hospital patients end up with an infection they didn't have when they arrived.

Among the most lethal of these is *Clostridium difficile*. The bacterium, which spreads easily in hospitals and other health-care facilities, was the source of almost half a million infections among patients in the United States in a single year, according to a 2015 report by the Centers for Disease Control and Prevention. Fifteen thousand deaths were directly attributable to the bug.

Jenna Wiens, an assistant professor of computer science and engineering at the University of Michigan, thinks hospitals could learn to prevent many infections and deaths by taking advantage of the vast amounts of data they already collect about their patients.

"I think to really get all of the value we can out of the data we are collecting, it's necessary to be taking a machine-learning and a data-mining approach," she says.

Wiens has developed computational models that use algorithms to search through the data contained in a hospital's electronic health records system, including patients' medication prescriptions, their lab results, and the records of procedures that they've undergone. The models then tease out the specific risk factors for *C. difficile* at that hospital.

"A traditional approach would start with a small number of variables that we believe are risk factors and make a model based on those risk factors. Our approach essentially throws everything in that's available," Wiens says. It can readily be adapted to different types of data.

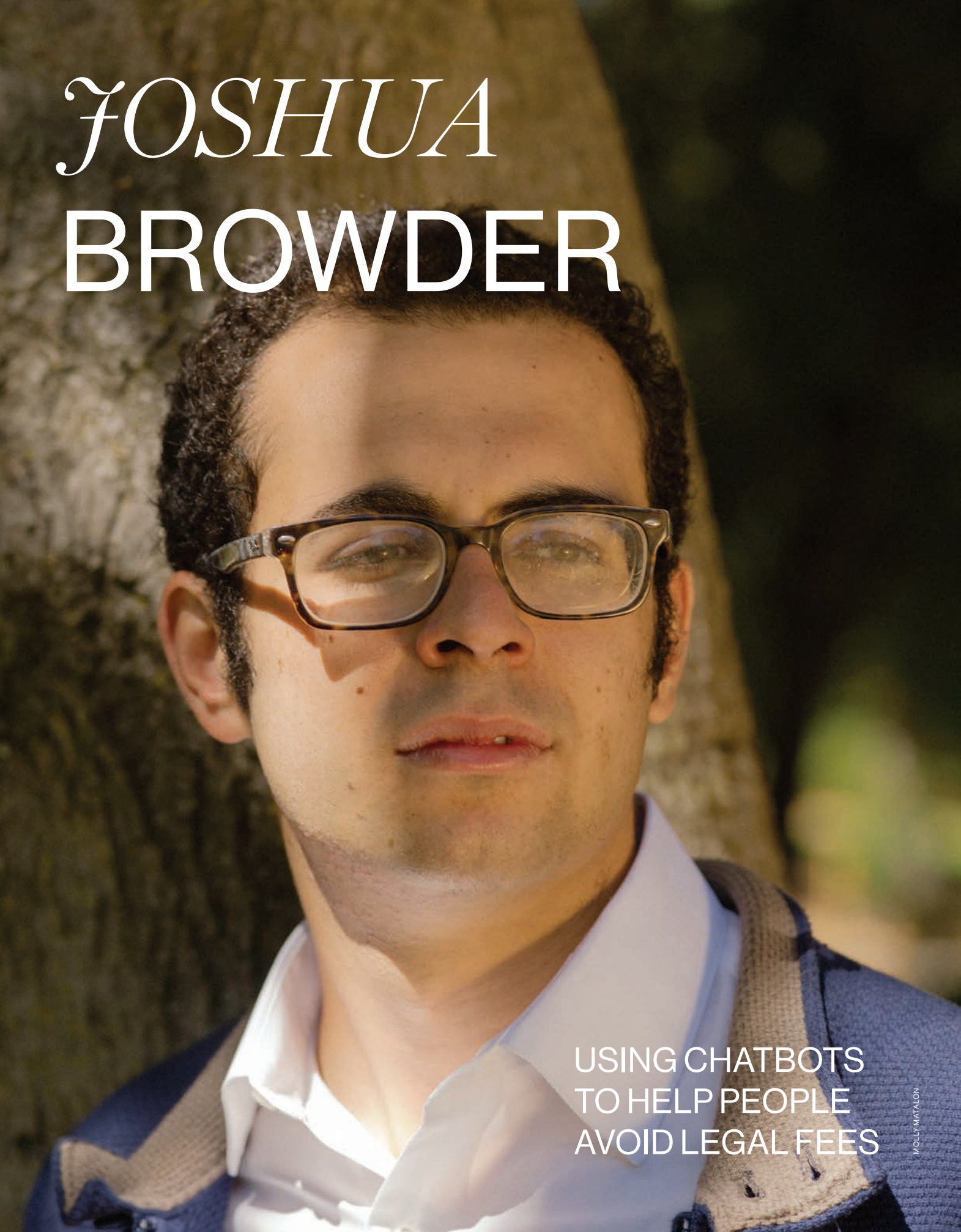
Aside from using this information to treat patients earlier or prevent infections altogether, Wiens says, her model could be used to help researchers carry out clinical trials for new treatments, like novel antibiotics. Such studies have been difficult to do in the past for hospital-acquired infections like *C. difficile*—the infections come on fast so there's little time to enroll a patient in a trial. But by using Wiens's model, researchers could identify patients most vulnerable to infections and study the proposed intervention based on that risk.

At a time when health-care costs are rising exponentially, it's hard to imagine hospitals wanting to spend more money on new machine-learning approaches. But Wiens is hopeful that hospitals will see the value in hiring data scientists to do what she's doing.

"I think there is a bigger cost to not using the data," she says. "Patients are dying when they seek medical care and they acquire one of these infections. If we can prevent those, the savings are priceless."

—Emily Mullin

Wiens has developed computational models that use algorithms to search through the data contained in a hospital's electronic health records system, including patients' medication prescriptions, their lab results, and the records of procedures they've undergone.



JOSHUA BROWDER

USING CHATBOTS TO HELP PEOPLE AVOID LEGAL FEES

MOLLY MATALON

Volodymyr Mnih

THE FIRST SYSTEM TO PLAY PONG AND SPACE INVADERS AS WELL AS A HUMAN CAN.

Volodymyr Mnih, a research scientist at DeepMind, has created the first system to demonstrate human-level performance in almost 50 Atari 2600 video games. Mnih's system was the first to successfully combine several AI techniques to mirror the way the human brain processes information—learning by example. His software learned to play the games much as a human would, through playful trial and error, while using the score as a measurement by which to hone and perfect its technique for each game. *—Simon Parkin*





Hanqing Wu

During a distributed denial of service (DDoS) attack, an attacker overwhelms a domain-name server with traffic until it collapses. The traditional way of fending off an attack like this is to pile up bandwidth so the server under attack always has more than enough volume to handle what the attacker has released. But as hackers become capable of attacks with bigger and bigger data volumes, this is no longer feasible.

Since the target of DDoS attacks is a website's IP address, Hanqing Wu, the chief security scientist at Alibaba Cloud, devised a defense mechanism through which one Web address can be translated into thousands of IP addresses. This "elastic security network" can quickly divert all benign traffic to a new IP address in the face of a DDoS attack. And by eliminating the need to pile up bandwidth, this system would greatly reduce the cost of keeping the Internet safe. *—Yiting Sun*

Joshua Browder is determined to upend the $200 billion legal services market with, of all things, chatbots. He thinks chatbots can automate many of the tasks that lawyers have no business charging a high hourly rate to complete.

"It should never be a hassle to engage in a legal process, and it should never be a question of who can afford to pay," says Browder. "It should be a question of what's the right outcome, of getting justice."

Browder started out small in 2015, creating a simple tool called DoNotPay to help people contest parking tickets. He came up with the idea after successfully contesting many of his own tickets, and friends urged him to create an app so they could benefit from his approach.

Browder's basic "robot lawyer" asks for a few bits of information—which state the ticket was issued in, and on what date—and uses it to generate a form letter asking that the charges be dropped. So far, 375,000 people have avoided about $9.7 million in penalties, he says.

In early July, DoNotPay expanded its portfolio to include 1,000 other relatively discrete legal tasks, such as lodging a workplace discrimination complaint or canceling an online marketing trial. A few days later, it introduced open-source tools that others—including lawyers with no coding experience—could use to create their own chatbots. Warren Agin, an adjunct law professor at Boston College, created one that people who have declared bankruptcy can use to fend off creditors. "Debtors have a lot of legal tools available to them, but they don't know it," he says.

"It should be a question of what's the right outcome, of getting justice."

Browder has more sweeping plans. He wants to automate, or at least simplify, famously painful legal processes such as applying for political asylum or getting a divorce.

But huge challenges remain. Browder is likely to run into obstacles laid down by lawyers intent on maximizing their billable hours, and by consumers wary of relying too heavily on algorithms rather than flesh-and-blood lawyers. *—Peter Burrows*

Austin Russell

A NEW KIND OF LASER SENSOR FOR SAFER SELF-DRIVING CARS.

Most driverless cars use laser sensors, or lidar, to map surroundings in 3-D and spot obstacles. But some cheap new sensors may not be accurate enough for high-speed use. “They’re more suited to a Roomba,” says Austin Russell, who dropped out of Stanford and set up his own lidar company, Luminar. “My biggest fear is that people will prematurely deploy autonomous cars that are unsafe.”

Luminar’s device uses longer-wavelength light than other sensors, allowing it to spot dark objects twice as far out. At 70 miles per hour, that’s three extra seconds of warning. *—Jamie Condliffe*





Jessica Brillhart

DEFINING THE TECHNIQUES FOR MOVIES IN VR.

Traditional filmmaking techniques often don’t work in virtual reality. So for the past few years, first as the principal filmmaker for virtual reality at Google and now as an independent filmmaker, Jessica Brillhart has been defining what will.

Brillhart recognized early on that in VR, the director’s vision is no longer paramount. A viewer won’t always focus where a filmmaker expects. Brillhart embraces these “acts of visitor rebellion” and says they push her to be “bold and audacious in ways I would never have been otherwise.” She adds: “I love how a frame is no longer the central concept in my work. I can build worlds.” *—Caleb Garling*

Fabian Menges

A THERMOMETER THAT WORKS AT THE NANOSCALE.

Problem: Complex microprocessors—like those at the heart of autonomous driving and artificial intelligence—can overheat and shut down. And when it happens, it’s usually the fault of an internal component on the scale of nanometers. But for decades, nobody who designed chips could figure out a way to measure temperatures down to the scale of such minuscule parts.

Solution: Fabian Menges, a researcher at IBM Research in Zurich, Switzerland, has invented a scanning probe method that measures changes to thermal resistance and variations in the rate at which heat flows through a surface. From this he can determine the temperature of structures smaller than 10 nanometers. This will let chipmakers come up with designs that are better at dissipating heat. *—Russ Juskalian*





Phillipa Gill

BRINGING SCIENTIFIC RIGOR TO THE STUDY OF INTERNET CENSORSHIP.

Five years ago, when Phillipa Gill began a research fellowship at the University of Toronto’s Citizen Lab, she was surprised to find that there was no real accepted approach for empirically measuring censorship. So Gill, now an assistant professor of computer science at the University of Massachusetts, Amherst, built a set of new measurement tools to detect and quantify such practices. One technique automatically detects so-called block pages, which tell a user if a site has been blocked by a government or some other entity. In 2015, Gill and colleagues used her methods to confirm that a state-owned ISP in Yemen was using a traffic-filtering device to block political content during an armed conflict. *—Mike Orcutt*



Safety never used to be much of a concern with machine-learning systems. Any goof made in image labeling or speech recognition might be annoying, but it wouldn't put anybody's life at risk. But autonomous cars, drones, and manufacturing robots have raised the stakes.

Angela Schoellig, who leads the Dynamic Systems Lab at the University of Toronto, has developed learning algorithms that allow robots to learn together and from each other in order to ensure that, for example, a flying robot never crashes into a wall while navigating an unknown place, or that a self-driving vehicle never leaves its lane when driving in a new city. Her work has demonstrably extended the capabilities of today's robots, enabling self-flying and self-driving vehicles to fly or drive along a predefined path despite uncertainties such as wind, changing payloads, or unknown road conditions.

As a PhD student at the Swiss Federal Institute of Technology in Zurich, Schoellig worked with others to develop the Flying Machine Arena, a 10-cubic-meter space for training drones to fly together in an enclosed area. In 2010, she created a performance in which a fleet of UAVs flew synchronously to music. The "dancing quadrocopter" project, as it became known, used algorithms that allowed the drones to adapt their movements to match the music's tempo and character and coordinate to avoid collision, without the need for researchers to manually control their flight paths. Her setup decoupled two essential, usually intertwined components of autonomous systems—perception and action—by placing, at the center of the space, a high-precision overhead motion-capture system that can perfectly locate multiple objects at rates exceeding 200 frames per second. This external system enabled the team to concentrate resources on the vehicle-control algorithms. *—Simon Parkin*

INVENTORS



COREY OLSEN

OLGA RUSSAKOVSKY

"It's hard to navigate a human environment without seeing," says Olga Russakovsky, an assistant professor at Princeton who is working to create artificial-intelligence systems that have a better understanding of what they're looking at.

A few years ago, machines were capable of spotting only about 20 objects—a list that included people, airplanes, and chairs. Russakovsky devised a method, based partly on crowdsourcing the identification of objects in photos, that has led to AI systems capable of detecting 200 objects, including accordions and waffle irons.

Russakovsky ultimately expects AI to power robots or smart cameras that allow older people to remain at home, or autonomous vehicles that can confidently detect a person or a trash can in the road. "We're not there yet," she says, "and one of the big reasons is because the vision technology is just not there yet."

A woman in a field dominated by men, Russakovsky started AI4ALL, a group that pushes for greater diversity among those working in artificial intelligence. While she wants greater ethnic and gender diversity, she also wants diversity of thought. "We are bringing the same kind of people over and over into the field," she says. "And I think that's actually going to harm us very seriously down the line."

If robotics are to become integral and integrated into our lives, she reasons, why shouldn't there be people of varying professional backgrounds creating them, and helping them become attuned to what all types of people need?

Russakovsky took a rather conventional path from studying mathematics as an undergrad at Stanford, where she also earned a PhD in computer science, to a postdoc at Carnegie Mellon. But, she suggests, "We also need many others: biologists who are maybe not great at coding but can bring that expertise. We need psychologists—the diversity of thought really injects creativity into the field and allows us to think very broadly about what we should be doing and what type of problems we should be tackling, rather than just coming at it from one particular angle." *—Erika Beras*

A woman in a field dominated by men, Russakovsky started AI4ALL, a group that pushes for greater diversity among those working in artificial intelligence.

Gregory Wayne

USING AN UNDERSTANDING OF THE BRAIN TO CREATE SMARTER MACHINES.

Greg Wayne, a researcher at DeepMind, designs software that gets better the same way a person might—by learning from its own mistakes. In a 2016 *Nature* paper that Wayne coauthored, it was demonstrated that such software can solve things like graph problems, logic puzzles, and tree structures that traditional neural networks used in artificial intelligence can't.

Wayne's computing insights play off his interest in connections between neurons in the human brain—why certain structures elicit specific sensations, emotions, or decisions. Now he often repurposes the concepts behind those brain structures as he designs machines. *—Caleb Garling*





Gene Berdichevsky

As employee number seven at Tesla, Gene Berdichevsky was instrumental in solving one of its earliest challenges: the thousands of lithium-ion batteries the company planned to pack into its electric sports car caught fire far more often than manufacturers claimed. His solution: a combination of heat transfer materials, cooling channels, and battery arrangements that ensured any fire would be self-contained.

Now Berdichevsky has cofounded Sila Nanotechnologies, which aims to make better lithium-ion batteries. The company has developed silicon-based nanoparticles that can form a high-capacity anode. Silicon has almost 10 times the theoretical capacity of the material most often used in lithium-ion batteries, but it tends to swell during charging, causing damage. Sila's particles are robust yet porous enough to accommodate that swelling, promising longer-lasting batteries. *—James Temple*

Michael Saliba

Crystalline-silicon panels—which make up about 90 percent of deployed photovoltaics—are expensive, and they're already bumping up against efficiency limits in converting sunlight to electricity. So a few years ago, Michael Saliba, a researcher at the Swiss Federal Institute of Technology in Lausanne, set out to investigate a new type of solar cell based on a family of materials known as perovskites. The first so-called perovskite solar cells, built in 2009, promised a cheaper, easier-to-process technology. But those early perovskite-based cells converted only about 4 percent of sunlight into electricity.

Saliba improved performance by adding positively charged ions to the known perovskites. He has since pushed solar cells built of the stuff to over 21 percent efficiency and shown the way to versions with far higher potential. *—Russ Juskalian*





Svenja Hinderer

Problem: Over 85,000 Americans receive artificial heart valves, but such valves don't last forever, and replacing them involves a costly and invasive surgery. In children, they must be replaced repeatedly.

Solution: Svenja Hinderer, who leads a research group at the Fraunhofer Institute in Stuttgart, Germany, has created a biodegradable heart valve that studies strongly suggest will be replaced over time by a patient's own cells.

To accomplish this, Hinderer created a scaffolding of biodegradable fibers that mimic the elastic properties of healthy tissues. To it she attaches proteins with the power to attract the stem cells that naturally circulate in the blood. The idea is that once implanted, her heart valve would be colonized and then replaced by a patient's own cells within two to three years.

—Russ Juskalian

IAN GOODFELLOW



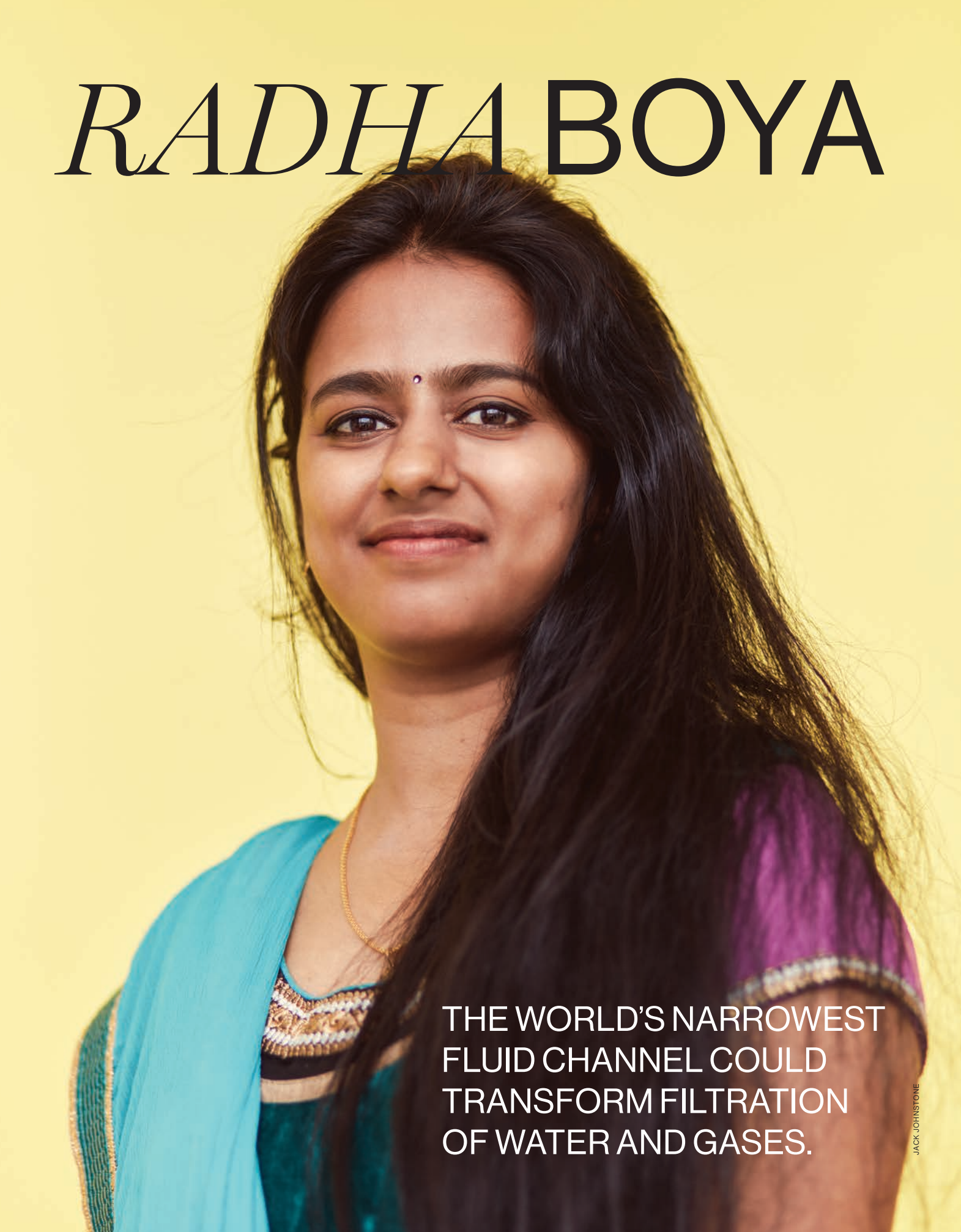
MOLLY MATALON

A few years ago, after some heated debate in a Montreal pub, Ian Goodfellow dreamed up one of the most intriguing ideas in artificial intelligence. By applying game theory, he devised a way for a machine-learning system to effectively teach itself about how the world works. This ability could help make computers smarter by sidestepping the need to feed them painstakingly labeled training data.

Goodfellow was studying how neural networks can learn without human supervision. Usually a network needs labeled examples to learn effectively. While it's also possible to learn from unlabeled data, this had typically not worked very well. Goodfellow, now a staff research scientist with Google Brain, wondered if two neural networks could work in tandem. One network could learn about a data set and generate examples; the second could try to tell whether they were real or fake, allowing the first to tweak its parameters in an effort to improve.

After returning from the pub, Goodfellow coded the first example of what he named a "generative adversarial network," or GAN. The dueling-neural-network approach has vastly improved learning from unlabeled data. GANs can already perform some dazzling tricks. By internalizing the characteristics of a collection of photos, for example, a GAN can improve the resolution of a pixelated image. It can also dream up realistic fake photos, or apply a particular artistic style to an image. "You can think of generative models as giving artificial intelligence a form of imagination," Goodfellow says. —*Will Knight*

RADHA BOYA



THE WORLD'S NARROWEST FLUID CHANNEL COULD TRANSFORM FILTRATION OF WATER AND GASES.

JACK JOHNSTONE

Beneath a microscope in Radha Boya's lab, a thin sheet of carbon has an almost imperceptible channel cutting through its center, the depth of a single molecule of water. "I wanted to create the most ultimately small fluidic channels possible," explains Boya. Her solution: identify the best building blocks to reliably and repeatedly build a structure containing unimaginably narrow capillaries. She settled on graphene, a form of carbon that is a single atom thick.

She positions two sheets of graphene (a single sheet is just 0.3 nanometers thick) next to each other with a small lateral gap between them. That is sandwiched on both sides with slabs of graphite, a material made of many layers of graphene stacked on top of each other. The result is a channel 0.3 nanometers deep and 100 nanometers wide, cutting through a block of graphite. By adding extra layers of graphene, she can tune the size of the channel in 0.3-nanometer increments.

But what fits through something so narrow? A water molecule—which itself measures around 0.3 nanometers across—can't pass through the channel without application of pressure. But with two layers of graphene, and a 0.6-nanometer gap, water passes through at one meter per second. "The surface of graphene is slightly hydrophobic, so the water

"I wanted to create the most ultimately small fluidic channels possible."

molecules stick to themselves rather than the walls," says Boya. That helps the liquid slide through easily.

Because the gaps are so consistently sized, they could be used to build precisely tuned filtration systems. Boya has performed experiments that show her channels could filter salt ions from water, or separate large volatile organic compounds from smaller gas molecules. Because of the size consistency, her technology can filter more efficiently than others.

Boya currently works at the University of Manchester's Graphene Research Institute in the U.K.—a monolithic black slab of a building that opened in 2015 to industrialize basic research on the material. It brands itself as the "home of graphene," which seems appropriate given that Boya's office is on the same corridor as those of Andre Geim and Kostya Novoselov, who won a Nobel Prize for discovering the material. *—Jamie Condliffe*



Franziska Roesner

"I'VE BEEN ASKING THE QUESTION, 'WHAT COULD A BUGGY OR MALICIOUS APPLICATION DO?'"

—Franziska Roesner, who leads a research group at the University of Washington and recognized early on that augmented reality will come with unique threats. She's led the thinking into what kind of security AR interfaces will need. *(as told to Rachel Metz)*

Lorenz Meier

AN OPEN-SOURCE AUTOPILOT FOR DRONES.

Lorenz Meier was curious about technologies that could allow robots to move around on their own, but in 2008, when he started looking, he was unimpressed—most systems had not yet even adopted the affordable motion sensors found in smartphones.

So Meier, now a postdoc at the Swiss Federal Institute of Technology in Zurich, built his own system instead: PX4, an open-source autopilot for autonomous drone control. Importantly, Meier's system aims to use cheap cameras and computer logic to let drones fly themselves around obstacles, determine their optimal paths, and control their overall flight with little or no user input. It has already been adopted by companies including Intel, Qualcomm, Sony, and GoPro. *—Russ Juskalian*



HUMANITARIANS



KATHERINE TAYLOR

COREY OLSEN

Irrigation shouldn't be a problem for the 30 million small farms in the water-rich Ganges River basin in eastern India. But today most farmers have to choose between cultivating a single crop each year during the monsoon rains and spending up to 90 percent of their profits to hire diesel or kerosene pumps during the dry seasons to access the plentiful, shallow groundwater.

Most plots stay uncultivated; to make up the income, farmers often resort to dangerous and demeaning migratory labor in diamond mines or clothing factories, leaving their families for months at a time.

This is what motivated engineer Katherine Taylor to uproot her life in the U.S. and move to India to found Khethworks, which builds an affordable solar-powered irrigation system that lets farmers cultivate year-round.

"Sometimes I get asked if I would have wanted a job at a high-tech company instead. But this was never a sacrifice for me, it was always the goal," says Taylor. "The potential for keeping families together, for having people doing work they feel is dignified—it's those kinds of stories we want to enable."

Originally, as part of the mechanical engineering master's program at MIT, Taylor focused on developing low-pressure drip irrigation systems, but during a visit to India, farmers helped her spot the real gap in the market. "They said, look, drip is great, but what we need is an affordable pump," she says. "Who cares about drip if we can't afford to irrigate year-round?"

In response, she and Khethworks cofounders Victor Lesniewski and Kevin Simon designed a centrifugal pump with triple the efficiency of similar-size pumps. That meant it could be powered by one-third as many photovoltaic panels—by far the most expensive component. This reduces the cost and makes the system portable so farmers can rent it out.

Taylor and Lesniewski moved to Pune in 2016 and will ship their first commercial product next spring.

Not that it's been easy. Endless red tape has been frustrating, she says, and they've had to adapt to a business culture with a different attitude toward deadlines. "The most important thing is having a good sense of humor," she says. But Taylor nevertheless believes it's "absurd" that bigger players haven't been designing for these farmers.

Going after these customers means Taylor and her cofounders haven't been able to stick to the standard advice for startups to focus on core competencies. It's likely they'll have to do everything from engineering to developing distribution models. "You don't necessarily have the luxury of doing exactly what you think you're best at," says Taylor.

—Edd Gent



Eyad Janneh

RESCUING ENDANGERED CIVILIANS IN SYRIA, USING LOCAL MATERIALS.

In the video, two flat black bags resembling large hot-water bottles expand slowly, gradually lifting a collapsed concrete-and-rebar wall and creating a space between the wall and a mound of rocks beneath. The film shows a test of a design by Eyad Janneh and his team at nonprofit Field Ready that is now being deployed in Syria, where it is used to lift heavy debris during searches for civilians following bomb attacks.

Janneh was raised in Syria but left in 2010 and now works in Istanbul. His team designs and tests tools that can be made locally from available materials. The airbags, for example, are made from a polyester fabric with a rubber sheet cover and some binding accessories—repurposing materials already being used as covers for cargo trucks. In April one of these airbags was used in Syria to help rescue two people trapped in rubble. *—Nanette Byrnes*

Suchi Saria

EXISTING MEDICAL DATA IS PUT TO WORK TO PREDICT SEPSIS RISK.

Problem: Sometimes the difference between life and death is a quick and accurate diagnosis. With sepsis, a life-threatening reaction to an infection, there's no definitive single test doctors can use to diagnose the condition.

Solution: Suchi Saria, an assistant professor at Johns Hopkins University, wondered: what if existing medical information could be used to predict which patients would be most at risk for sepsis? Algorithms that she subsequently created to analyze patient data correctly predicted septic shock in 85 percent of cases, by an average of more than a day before onset. That is a 60 percent improvement over existing screening tests. *—Emily Mullin*



Reviews



A Different Story from the Middle East: Entrepreneurs Building an Arab Tech Economy

Startups are overcoming cultural and other barriers to tap into a growing local taste for technology, from Bitcoin wallets to digital publishing.

By Christopher M. Schroeder

PHOTOGRAPH BY TOM DULAT | GETTY

MIT TECHNOLOGY REVIEW
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At the end of March, it was announced that the largest e-commerce company in the Middle East and North Africa, Souq.com, would be acquired by Amazon for nearly $600 million. This was unusual: when Amazon enters a new geographic market, it typically does so by launching its existing platform and investing a lot of money to grow it. Instead, Amazon—apparently impressed by Souq.com's management team, its technology, and its ability to navigate a complicated region—decided on a different strategy.

A week after the announcement, at the Step Conference in Dubai, one of the most popular startup gatherings in the region, it felt as if lightning had struck. Over 2,000 aspiring entrepreneurs filled the arena, standing room only, for a panel with Souq.com founder Ronaldo Mouchawar. Mouchawar, a native of Aleppo, Syria, spent over an hour onstage with his cofounders and lead investor, explaining in painstaking detail what it was like to build an e-commerce giant. In 2005, when Souq.com launched, few in the Arab world were shopping digitally, fewer still were willing to use a credit card online, and examples of successful tech startups were hard to find. Now, Mouchawar underscored to his rapt audience, things were different.

A few months earlier, Careem—the region's fast-growing ride-sharing company—had been valued by venture capitalists at over $1 billion. To those at the conference, these two recent successes seemed to signal a turning point in the Arab world, made possible by local access to technology and a rising middle class. One young woman, an aspiring entrepreneur taking copious notes on her laptop, told me, "I can do this. I will do this."

Of course, the challenges in the region remain very real, among them poverty, war, and the breakdown of political and economic institutions. Israel has a well-established technology sector, but in the Arab Middle East—outside the United Arab Emirates and its leading economic center, Dubai—the legal and regulatory system is at best cumbersome to navigate, and more often unpredictable and inconsistent. Historic political disputes and security concerns are issues as well. Educational infrastructure, despite relatively heavy spending, is not adequate for developing a 21st-century workforce.

Yet something encouraging is happening. Everywhere in Dubai, young people gather, checking their smart devices. You can see them walking the sandy corniche by the sea, enjoying the park-like beauty of the recently completed canal, or sitting at any stylish café. Two generations ago it was a small trade and pearling center surrounded by desert, but today this city on the Persian Gulf has grown into a hub from which tech startups with roots across the Middle East look toward rising markets to the east, west, north, and south. Souq.com and Careem are but two of thousands. And, like Amazon, global tech players including Google, Facebook, and LinkedIn have all been expanding their presence here significantly.

The vast majority of the city's three million residents, including a new generation of young Arab entrepreneurs, were born elsewhere. And they are selling to a wired generation across the Middle East. In nearly every country in the region today, more than half of the population is under 30, according to the United Nations Development Programme. Nearly two-thirds of them will have smart devices by the end of this decade, according to predictions by the global mobile trade association GSMA, a figure already exceeded in parts of the Gulf today but much lower in Egypt and other countries. Immigrant





(Top) Amazon executive Russ Grandinetti (left) shakes hands with Ronaldo Mouchawar, founder of Souq.com. (Bottom) Careem cofounders Mudassir Sheikha (left), Abdulla Elyas (center), and Magnus Olsson (right).

IMAGE COURTESY OF SOUQ.COM; IMAGE COURTESY OF CAREEM

entrepreneurs are using Dubai as a platform from which to reach customers, often leveraging technology, talent, and affordable operations in their home countries while taking advantage of their own knowledge about local markets.

Two decades ago, making it in global technology fundamentally meant selling to America. Now, and increasingly, connected consumers are everywhere—India, Southeast Asia, Africa. Dubai is within a four-hour flight of over one-third of the world's population. According to the research arm of the Step Conference, Dubai and the rest of the UAE are home to over 42 percent of all startups in the Arab world. The research group Magnitt estimates that of the 60 technology companies acquired in the region over the past five years, most are headquartered in Dubai. In the next year, as much as $1 billion in new venture money is projected to be raised from investors in the region for investment in local startups—a large number for any developing economy, and a big jump from 2016 levels.

Bankruptcies and visas

The UAE's government has recently made legal changes to encourage entrepreneurship. In 2016, the government enacted its first bankruptcy law. The freedom to fail, learn from failure, and quickly start the next enterprise has been crucial to the Silicon Valley blueprint, but in some parts of the Middle East, cultural traditions around debt and obligations to others had made failure a criminal act: executives could literally serve prison time. And during a time when some in America are fighting any expansion of H1-B visa programs, which allow foreigners to work in the country in specialized occupations, the UAE just announced a new visa offering residency to the best technologists from anywhere on earth.

The Dubai government is embracing technology too. By the end of 2020, all government documentation and interactions will be available on blockchain, a decentralized record-keeping technology that verifies and records transactions securely. By 2019, as part of a strategy to improve efficiency and construction safety while reducing costs, 2 percent of all new construction will have to use 3-D-printed components in order to receive building permits, a number set to increase each year until it reaches 25 percent by 2030. The UAE even has its own space program; it plans to expand satellite efforts and launch the first Mars probe in the Arab world.

Ala' Alsallal, 31, is one of thousands of entrepreneurs here combining operations headquartered in their home country, in his case Jordan, with an office in Dubai. His startup, the online book market Jamalon (Arabic for "top of the pyramid"), began seven years ago and now offers over 12 million titles, including over 150,000 in Arabic. Amazon, by comparison, has only a few hundred.

One young aspiring entrepreneur taking copious notes on her laptop told me, "I can do this. I will do this."

Alsallal comes from a modest background. He is one of seven children born to Palestinian schoolteachers whose grandparents had come to Jordan after the formation of Israel in 1948. Such Palestinian refugees represent nearly a third of Jordan's population, and many live today in refugee "camps" that are really settlements with buildings, electricity, and water, built on the hill locally called the "Jabal." These communities are cramped, poor, and self-contained. Schools are run down and there are few safe places for children to play, so it is no surprise that both dropout rates and unemployment are staggeringly high.

Alsallal, gifted in math and science, realized that all the traditional paths to success in Jordanian society—medicine, law, and engineering—would be unaffordable and unreachable for him. But he convinced his family to pull together money for the limited online access possible in his community and used that to learn about the broader world of technology. He studied engineering on scholarship at Athens Information Technology (an affiliate of Carnegie Mellon University) and, after two years working in Greece, returned home to Amman, Jordan's capital, to start his own company.

Amazon had long impressed him, and while the online merchant had a small presence in the region, he was vexed at how hard it was to find books in Arabic online. Sketching out a simple business plan, Alsallal persuaded angel investors and mentors like Fadi Ghandour, founder of the express delivery company Aramex, to give him a few tens of thousands of dollars to begin. (Ghandour is also chairman of the investment firm Wamda Capital, which focuses on this region, and on whose board of advisors I serve.) Last year, Alsallal raised over $4 million more to expand Jamalon's operations.

In Dubai, he opened the region's first "print on demand" operation, allowing books to be printed at lower cost for easier shipment in the UAE, across the region, and around the globe. Last spring, when the German publisher OmniScriptum was interested in entering the market, executives discovered that it was cheaper to work with Jamalon than to ship via DHL from Frankfurt to the Middle East. Working with Jamalon on Arabic printing, OmniScriptum is saving 80 percent of the shipping costs it would have paid and benefiting from the market expertise of a local partner, says COO Marc Wegmann.

Over a thousand miles northwest of Jamalon's Dubai facility, in a building with the simple white façade typical of

Amman, is what Alsallal calls "our kitchen in the background." Tapping into local software talent and taking advantage of lower local salaries, Alsallal has kept his back-end operations—call center, supply-chain management, procurement, and finance—in his hometown. A good software engineer or procurement operator can thrive on $35,000 a year in Amman—a sum that would barely cover the living expenses for two months in Dubai.

Of Jamalon's 70 employees, 65 are in Amman, and their number is growing. The office walls are painted in the signature light purple of the brand. Desks are simple but equipped with the latest technology. "Operationally, we had to move to Dubai to grow," Alsallal says, citing laws that encourage shipping and delivering, as well as the city's advantage in logistics. "But it wasn't easy culturally. The founding, the history, the connectedness of the team was all in Amman—I hired nearly everyone," he says. When textbook publishing began to ramp up quickly in Dubai, an "us vs. them" mentality developed. Alsallal brought the small Dubai team to Amman to address the issue. "They worked together, went out together, communicated face to face. Lots of clashes went out the window due to this," says Alsallal. "The combination of a strong hub in Dubai and operations on the ground in each country is powerful and gives us a significant advantage. There is nothing like [Dubai] in the Middle East—nothing really like it anywhere."

That dynamic is why Hassan Hamdan, cofounder of Saudi Arabia–based Unifonic, is moving his company and his own residence to Dubai. The cloud communications company, which has revenue reported to be in the tens of millions, is a kind of one-stop shop for mobile marketing, including a particularly popular service that sends millions of messages in an instant. Hamdan is a lanky, eloquent, restless computer nerd who began playing with computers in 1997 as a 10-year-old in Jeddah, Saudi Arabia. By 1998, his family had broadband access to the Internet, and he quickly found communities and forums of like-minded young people who helped him learn English, answered questions on how to code, and taught him how to design.

Hamdan's business career got its start around 2006, when his brother Ahmed, a student at King Fahd University of Petroleum and Minerals, called him with a problem. He wanted to text the entire student body about an event but could only reach them one at a time, a task that would take hours. Hamdan designed a basic website where one could put in all the students' data, and messages would be sent out in one shot. People outside the university began to find the website by word of mouth and use it for wedding invitations, family gatherings, and events in their workplaces. "It wasn't a business yet, because I hadn't figured out I could charge for it," says Hamdan. "But thousands were using it. None of us had an idea about Evite or early services in the West, because few of us spoke English. It really took off."

"There is nothing like Dubai in the Middle East—nothing really like it anywhere."
—Ala' Alsallal, founder, Jamalon

Shortly thereafter, with Hamdan himself in college in Egypt, the brothers decided to launch a business, recruiting Hamdan's university classmates to build the technology. In 2010, the brothers got their big break: a contract with Toyota Saudi Arabia, which had learned about their business from an employee who used the tool for wedding invitations. Today they are selling to automakers, financial firms, and many others in a number of countries, including Egypt, Sudan, Qatar, the UAE, Jordan, and Bahrain.

"To reach anywhere in the Arab world, Pakistan, Africa, Southeast Asia, there was only one clear choice for us," Hamdan says. "In one flight, you can get to India, Kenya, South Africa, Nepal, Pakistan, Singapore, Malaysia, and Indonesia easily." He pauses. "But what people underestimate about it is the accessibility of talent here from a wide range of nationalities. This global talent offers skill sets unheard of on this side of the world, but also talent that is connected to their homes, speaks their languages. There is a diversity and pool from which you can pick and choose exactly for your expansion needs for any emerging market."

Female entrepreneurs

It surprises many in the West that over 25 percent of startups in the Arab world are reported by the *Economist* to be founded or led by women. By contrast, tech researcher Crunchbase estimates that number at closer to 17 percent in the United States. Hala Fadel, cofounder of Leap Ventures, a leading venture capital firm based in Beirut, says that as a relatively new field in the region, technology has no legacy of being male dominated, and it embraces a culture of freedom where everything is viewed as possible, including breaking gender barriers. "It is almost the only space where this is possible in the region," Fadel says. "It is therefore very compelling to women." Middle-class Arab women who want to work here often have little opportunity, especially since the unemployment rate is high, so many are starting tech or tech-enabled businesses in their own homes.

Ola Doudin founded her company, BitOasis, when she spotted a gap in the financial infrastructure of the region and identified a rising new technology to fill it. Originally from Amman, Doudin studied electronic engineering at the University



Technology embraces a culture of freedom attractive to female entrepreneurs in the region, says Hala Fadel, cofounder of Beirut-based VC firm Leap Ventures.

IMAGE COURTESY OF SOLVE MIT

of Birmingham in the United Kingdom, later training herself to code. She bristled against the Middle East's educational emphasis on rote learning and memorization, and she sought to push beyond the traditional career paths in government, engineering, or large companies that most parents wanted their kids to follow. In 2015, she began to explore the potential in the region for blockchain technology and cryptocurrencies such as Bitcoin.

In 2015, at a time when more than half the population of the Middle East had access to the Internet but less than 20 percent had bank accounts, something seemed to Doudin to be fundamentally broken. Banks were inefficient and costly and showed little interest in catching up with the digital transformation happening globally. The fast-growing Internet user base was already eagerly looking for alternatives to traditional banking—channels, especially online, that were accessible, instant, global, and efficient. "Bitcoin checks all those boxes and more," she says. BitOasis, which she founded in 2015, was one of the first Bitcoin wallets and exchanges in the Middle East and North Africa. As of June 2017, it is processing over $60 million per month, and volume has doubled every month.

To Doudin, the advantages of Dubai are obvious: its diverse market, global market reach, melting pot of talent, and young community of entrepreneurs make it an easier place to launch a new product or test a new technology. "It is also a young city with the character of an entrepreneur," she says. It is "not afraid of taking risks and always trying to push the limits."

Entrepreneurs like these—the size of the opportunities they are working on and the market dynamic of a rising consumer middle class—have long intrigued me as an investor. But their stories are also a reminder that in rising regions things are often much different on the ground from what we read in the news—that checking our bias can help us understand the challenges and see the potential.

I think back to my most recent ride in a Careem car last year. Even with all my visits to Dubai, the pace of change still astounds—the rapid infrastructure growth, the clip of business dealings, the seemingly infinite number of places to dine and drink, the aggregation of wealth. Careem's fleet, all clean and efficient Lexuses, is the most reliable way for global executives—for anyone—to get from point A to point B. That day, we were heading to the city's newest business hub, passing skyscrapers, palm trees, and the buzz of young business executives hurrying across the streets. My driver asked me to look at his dashboard, where his GPS screen displayed the road we were on. Instead of skyscrapers and development, it showed everything around the road as brown desert.

He smiled. "This is less than two-year-old software—last time I loaded this, nothing was here," he said. "It is only the beginning."

Christopher M. Schroeder is an American entrepreneur and global investor. His book Startup Rising: The Entrepreneurial Revolution Remaking the Middle East *was the first to document the rise of tech startups and innovation in the Arab world.*


KRISTIAN HAMMERSTAD



Growing Up with Alexa

What will it do to kids to have digital butlers they can boss around?

By Rachel Metz

When it comes to digital assistants like Ama-zon's Alexa, my four-year-old niece Hannah Metz is an early adopter. Her family has four puck-like Amazon Echo Dot devices plugged in around her house—including one in her bedroom—that she can use to call on Alexa at any moment.

"Alexa, play 'It's Raining Tacos,'" she commanded on a recent sunny afternoon, and the voice-controlled helper immediately complied, blasting through its speaker a confection of a song with lines like "It's raining tacos from out of the sky" and "Yum, yum, yum, yum, yumidy yum."

Giggling and clapping, Hannah danced around the room. I think this ability to get music on demand is neat, too, and I didn't want to be rude, so I danced with her. But at the same time I was wondering what it's going to mean for her to grow up with computers as servants.

The research firm eMarketer estimates that 60.5 million people in the U.S.—a little less than a fifth of the population—will use a digital assistant at least once a month this year, and about 36 million will do so on a speaker-based device like Amazon Echo or Google Home. These things are most popular among people age 25 to 34, which includes a ton of parents of young children and parents-to-be.

And these techno-helpers are not just going to get more popular; they will also get better at responding to queries and orders, and they'll sound more humanlike, too. At the

same time, young users like Hannah will become more comfortable and sophisticated with the technology, going beyond telling Alexa to play a song. They'll request help with homework or control devices around their home.

It's a little worrisome. Leaving aside the privacy implications of kids telling an Internet-connected computer all kinds of things, we don't know much about how this kind of interaction with artificial intelligence and automation will affect how children behave and what they think about computers. Will they become lazy because it's so easy to ask Alexa and its peers to do and buy things? Or jerks because many of these interactions compel you to order the technology around? (Or both?)

Some of that may happen. It seems more likely, though, that as with many technologies before this, the utility of digital assistants will outweigh their drawbacks. Already they're making an incredible amount of data and computer-aided capabilities available directly to children—even those not yet in kindergarten—for learning, playing, and communicating. With Alexa, kids can get answers to all kinds of questions (both serious and silly), hear stories, play games, control apps, and turn on the lights even if they can't yet reach a wall switch. And this is just the beginning of the kiddie AI revolution.

Alexa

"Hey Google is it OK if I eat you?': Initial Explorations in Child-Agent Interaction"
Stefania Druga, Randi Williams, Cynthia Breazeal, and Mitchel Resnick
Proceedings of the 2017 Conference on Interaction Design and Children
June 2017

Does Alexa have feelings?

I wasn't sure if Hannah knew whether Alexa is human. So I asked, and this is what she told me: Alexa is "a kind of robot" who lives in her house, and robots, she reasoned, aren't people. But she does think Alexa has feelings, happy and sad. And Hannah says she would feel bad if Alexa went away. Does that mean she has to be nice to Alexa? Yes, she says, but she's not sure why.

Her interest in her digital assistant jibes with some findings in a recent MIT study, where researchers looked at how children ages three to 10 interacted with Alexa, Google Home, a tiny game-playing robot called Cozmo, and a smartphone app called Julie Chatbot. The kids in the study determined that the devices were generally friendly and trustworthy, and they asked a range of questions to get to know the technologies ("Hey Alexa, how old are you?") and figure out how they worked ("Do you have a phone inside you?").

Cynthia Breazeal, one of the researchers and director of the Personal Robots Group at MIT's Media Lab (as well as cofounder and chief scientist of the company developing an AI robot called Jibo), says that it's not new for children to anthropomorphize technology. But now it's happening a little differently.

For young kids like Hannah who can't yet read, write, or type but can talk a mile a minute, voice-operated assistants could help build social skills and push boundaries—two things that are key to a child's development. If nuances in the user's tone can affect how the digital servants respond—which is not that unlikely in the near future—it's possible that kids who use them will become more adept at communicating with others (be the others humans or robots).

That would be a change from what Breazeal sees today: a lot of bad behavior when we interact with each other using technology. She thinks that arises from the abstract context of, say, tweeting,



Children in the MIT Media Lab study using a Google Home device. The researchers hope to eventually design such digital agents so that kids will be able to tinker with them.

RANDI WILLIAMS



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where we may not fully appreciate the consequences of our interactions. She sees a huge opportunity for virtual assistants like Alexa, Google Home, and others to be designed in ways that push us to treat others the way we want to be treated.

Even though that isn't the way Alexa works yet, it is teaching Hannah some things about how to treat machines, at least. Her mom, Susan Metz, tells me that she's learning there's a special pattern you have to use when asking Alexa things (you have to say a keyword like "Alexa" first), so she is figuring out that this voice assistant isn't something you can speak to the way you would a person. Hannah has also learned that she has to be quiet when her mom is talking to Alexa (I can confirm this isn't carrying over to times that Susan is talking with people). It is possible that simple, routine interactions with this kind of AI will help kids learn even without much advancement in the technology or its design.

Hannah uses Alexa to find out the time and date. That makes Elizabeth Vandewater, director of data science and research services at the University of Texas at Austin's Population Research Center, wonder if easy access to these assistants will help some kids develop a sense for things like calendar days and minutes sooner than they would have previously. In a way that's helpful—it's one less question peppering parents from a talkative kid. And in fact, Susan says she's happy that Alexa entertains Hannah. But it also brings a sense of robotic precision to life that most of us don't really have to deal with until we're older and more independent, entrusted with doing things like getting to school or work on time. Who knows if that's a good thing?

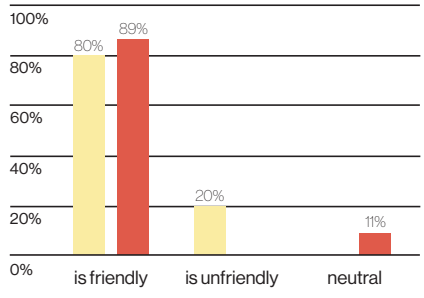
Say what?

No matter how you're using these digital butlers, the limits of the technology quickly become apparent. Voice-led interactions can still be difficult even for the clearest-speaking adults, and young kids don't often enunciate that well.

Hannah had this problem a few times when she asked Alexa to play music from the Disney movie *Moana* and Alexa had no idea what she was trying to say. Hannah responded by doing what a lot of us would do when speaking to someone who can't understand us: she spoke a lot louder, and slower. It still didn't work, and Hannah got frustrated.

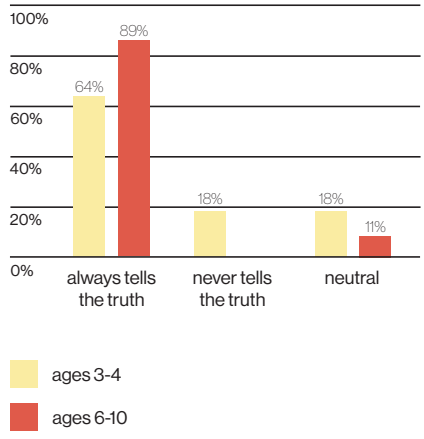
Are digital assistants friendly?

When MIT researchers asked kids how they felt about assistants such as Alexa, they got the following responses.



How often are agents truthful?

Children in the study tended to believe what the assistants said. The younger kids were less sure.



How to fix it? Breazeal and the other MIT researchers suggest that Alexa and similar "agents" could be designed to tell you why they don't understand what you're asking or commanding, so you can better determine how to get what you want. This makes a lot of sense, as we're innately social (and like feedback), and it's important to learn how to communicate with others in a way that takes their capabilities and levels of understanding into account.

What about older children? Will they get bossy and bratty from the habit of ordering Alexa around? Probably not, says Kaveri Subrahmanyam, a developmental psychologist and chair of child and family studies at California State University, Los Angeles. But she does wonder whether having digital butlers will reduce kids' ability to do things for themselves. "I don't think we have to be worried about it or paranoid about it, but I do think it's something to be watchful for," she says.

The other researchers I spoke to aren't too worried either. "There's this notion that if all this technology was turned off, everything would be great. We'd be interacting all the time, we'd be reading all the time," Vandewater says. "I just don't believe that."

In fact, maybe the opposite can be true. Perhaps growing up with Alexa will actually make technology less distracting, enabling it to, in a sense, fade into the background; we'll get what we need from it, and then move on with our lives until we come back with another request.

For Hannah, at least, this seems to be the case for now. She didn't want to spend much time inside playing with Alexa, and so shortly after we finished dancing to "It's Raining Tacos," she ran outside to chase her little brother around the yard.

Rachel Metz is senior editor for mobile at MIT Technology Review.

DATA FROM "HEY GOOGLE IS IT OK IF I EAT YOU" STUDY OF 26 CHILDREN AGES THREE TO 10. EACH CHILD WAS ASKED ABOUT TWO SERVICES



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The Myth of the Skills Gap

The idea that American workers are being left in the dust because they lack technological savvy does not stand up to scrutiny. Our focus should be on coordination and communication between workers and employers.

By Andrew Weaver

The contention that America's workers lack the skills employers demand is an article of faith among analysts, politicians, and pundits of every stripe, from conservative tax cutters to liberal advocates of job training. Technology enthusiasts and entrepreneurs are among the loudest voices declaiming this conventional wisdom (see "The Hunt for Qualified Workers," November/December 2014).

Two recent developments have heightened debate over the idea of a "skills gap": an unemployment rate below 5 percent, and the growing fear that automation will render less-skilled workers permanently unemployable.

Proponents of the idea tell an intuitively appealing story: information technology has hit American firms like a whirlwind, intensifying demand for technical skills and leaving unprepared American workers in the dust. The mismatch between high employer requirements and low employee skills leads to bad outcomes such as high unemployment and slow economic growth.

The problem is, when we look closely at the data, this story doesn't match the facts. What's more, this view of the nation's economic challenges distracts us from more productive ways of thinking about skills and economic growth while promoting unproductive hand-wringing and a blinkered focus on only the supply side of the labor market—that is, the workers.

Although much research touches on this topic, almost none of the existing studies directly measure skills, the key quantity of interest. I have conducted a series of nationally representative skill surveys covering a range of technical occupations: manufacturing production workers, IT help-desk technicians, and laboratory technologists. The surveys specifically target managers with knowledge of both hiring and operations at their businesses. The basic strategy is to ask: what skills do employers demand, and do the employers that demand high skill levels have trouble hiring workers?

The results yield a number of surprises. First, persistent hiring problems are less widespread than many pundits and industry representatives claim. A few years back, Paul Osterman of MIT's Sloan School of Management and I found that less than a quarter of manufacturing plants had one or more production-worker vacancies that had

"Skill Demands and Mismatch in U.S. Manufacturing"
By Andrew Weaver and Paul Osterman
ILR Review
2016

"Community Colleges and Employers: How Can We Understand Their Connection?"
By Paul Osterman and Andrew Weaver
Industrial Relations
2016



lasted for three months or more. By contrast, industry claims at the time were that three-quarters or more faced a persistent inability to hire skilled workers.

More recently, I have looked for signs of hiring trouble in IT and clinical laboratory occupations. Given a tighter labor market and higher educational requirements for these entry-level technical jobs, it would be reasonable to expect hiring to be more difficult. Not so. Only 15 percent of IT help desks report extended vacancies in technician positions. While the results do show higher levels of long-term lab-tech openings, it turns out that many of these are concentrated in the overnight shift and thus reflect inadequate compensation for difficult working conditions, not a structural skill deficiency. A little over a quarter of clinical diagnostic labs report at least one long-term vacancy.

The survey results do show some hiring challenges, but not for the reasons posited by the conventional skill-gap narrative. In fact, the data reveal that high-tech and cutting-edge establishments do not have greater hiring difficulties than other establishments. Furthermore, the data imply that we should be careful about calling for more technical skills without specifying which skills we are talking about. It is quite common to hear advocates—and even academics—assert that the answer to the nation's labor-market and economic-growth challenges is for workers to acquire more science, technology, engineering, and mathematics (STEM) skills. However, my data show that employers looking for higher-level computer skills generally do not have a harder time filling job openings. Manufacturers requiring higher-level math do sometimes have more hiring challenges, but math requirements are not a problem for IT help desks or clinical labs.

So what are the skill requirements most consistently associated with hiring difficulties? In manufacturing, it's higher-level reading, while for help-desk technicians it's higher-level writing. Proponents of the skill-gap theory sometimes assert that the problem, if not a lack of STEM skills, is actually the result of a poor attitude or inadequate soft skills among younger workers. But while demand for a few soft skills—like the ability to initiate new tasks without guidance from management—is occasionally predictive of hiring problems, most soft-skill demands, including requirements for cooperation and teamwork, are not.

This is not to say that STEM or soft skills are not enormously useful. However, specific recommendations and courses of study need to be tightly connected to particular occupational requirements and employer needs. For example, although it may seem safe to recommend that students go learn some kind—any kind—of computer programming, following that advice won't necessarily open up a job opportunity as, say, an IT help-desk technician, a position that happens to be the second-largest computer/mathematical occupation in America. Only 15 percent of computer help desks demand programming, a number that is slightly lower than the percentage of manufacturing plants that require programming skills for their production workers. Knowledge of networking processes and operating systems, along with writing skills, is far more likely to meet the requirements of help-desk hiring managers.

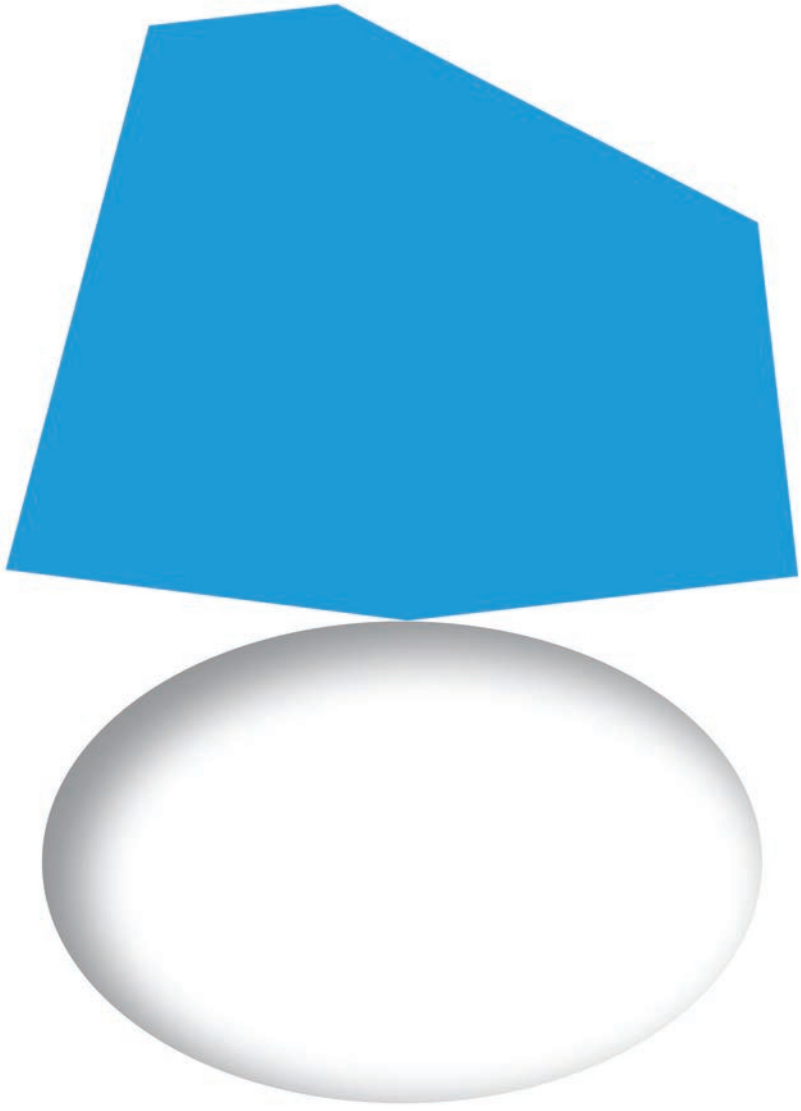
There is also a lot of variation in skill levels demanded within each occupation. For example, only about a third of IT help desks and manufacturing plants require higher-level math, such as algebra or statistics. Thus, we cannot assume that a single occupational skill requirement applies to all establishments, or that workers in every market are getting a consistent signal about skill requirements.

As a variety of results in economic and management research have shown, employers are surprisingly capable of designing jobs in different ways to make use of different skill sets. We would ultimately like to ratchet up both employer skill requirements and employee skill levels (and the corresponding productivity and wages), but doing so requires that we think not only about adjusting worker skill levels, but also about changing employer behavior.

This points up the danger in the way we currently discuss the "skills gap." Thinking about the nation's economic and workforce challenges this way encourages us to believe that the root of all labor-market problems lies in the low quality of labor supply—that is, in workers' lack of skills. However, pushing students and new workers to unilaterally make expensive investments in generic skill categories (or, worse, to just get "more education") is likely to result in inefficient investments, mistaken choices, and a large number of dead-end paths.

Even economists and labor-market experts don't know the exact mix or level of skills that particular occupations demand. No regularly administered government survey can tell us, say, the percentage of clinical laboratories that require lab techs to know probability or statistics (55 percent, according to my research), or the percentage of IT help desks that demand knowledge of mobile operating systems (76 percent). Ultimately, there is no substitute for coordination between the supply side of the labor market (workers and their skill investments) and the demand side (employers and their skill requirements). Rather than blaming workers and schools, we should be focusing on labor-market intermediaries such as employment agencies or trade associations, employer relationships with technical colleges or other institutions, and

This view of the nation's economic challenges distracts us from more productive ways of thinking about skills and economic growth while promoting unproductive hand-wringing.



employer-provided training. In this regard, my survey results do give cause for concern.

The manufacturing survey data indicate that only half of U.S. plants provide formal training to their production workers. By contrast, in the 1990s—the last period for which nationally representative survey data on training are available—70 to 80 percent did so. Meanwhile, only 52 percent of IT help desks have relationships with institutions from which they hire workers or receive training services. For clinical labs, the absence of a local training institution is a significant predictor of hiring difficulties.

Instead of fretting about a skills gap, we should be focused on the real challenge of knitting together the supply and demand sides of the labor market. Thinking about the real financial and institutional mechanisms necessary to make, say, apprenticeships work is far more productive than perennially sounding alarms about under-skilled workers.

A final point is worth making on technology and the fear that robots will steal all the jobs. Occupations evolve as technology advances. Help-desk technicians once spent more time on tasks like password resets than they do today. Despite the automation of such functions, computer problems—and the occupation that tackles them—continue to expand.

The danger is not that we will run out of tasks humans can usefully perform or that required skill levels will be catastrophically high; it's that misguided anxiety about skill gaps will lead us to ignore the need to improve coordination between workers and employers. It's this bad coordination—not low-quality workers—that presents the real challenge.

Andrew Weaver is an assistant professor in the School of Labor and Employment Relations at the University of Illinois at Urbana-Champaign.



To Feed the World, Improve Photosynthesis



By reworking the basic metabolism of crops, plant scientists hope to forestall devastating food shortages.

By Katherine Bourzac
Photographs by Whitten Sabbatini


1

Inside a balmy greenhouse in central Illinois, a boisterous but focused pair of researchers are seeding experimental plants. The scientists moisten the soil and pack it into pots, then carefully tip tiny dark-brown tobacco seeds out of glass vials. In the months that follow, the researchers will move the plants outside into a field and watch whether they grow bigger or faster than usual—a crucial step toward feeding the world of 2050.

These tobacco plants have been engineered at a more fundamental level than typical biotech crops. The way they conduct photosynthesis has been tinkered with so they convert sunlight and carbon dioxide more efficiently into carbohydrates. If scientists do that in food crops, any given plot of land could produce more food, or produce the same amount of food with less water and fertilizer.

The need is urgent. To feed a growing population, the United Nations projects, worldwide agricultural yields must increase by 50 percent between now and 2050. And that ambitious goal does not factor in the effects of climate change. Plants thrive on carbon dioxide, but very hot days suppress crop yields. In many parts of the world, the rising temperatures and increased droughts caused by climate change will be devastating. And those negative effects "will have the biggest impact on the poor," says Steve Long, director of the Realizing Increased Photosynthetic Efficiency (RIPE) project, an international consortium based at the University of Illinois at Urbana-Champaign.

The RIPE project, funded by the Bill and Melinda Gates Foundation, is starting with tobacco because it's relatively easy to genetically engineer. But RIPE's real aim is to improve the yields of food crops such as cassava and cowpeas, which are important sources of calories and protein in many poor countries. And it is working on much more ambitious





HALEY AHLERS (3)

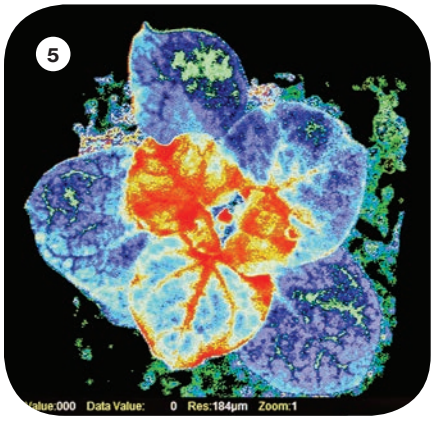
Opening spread A field of soybeans is part of an experiment to test the effects of climate change on photosynthesis.

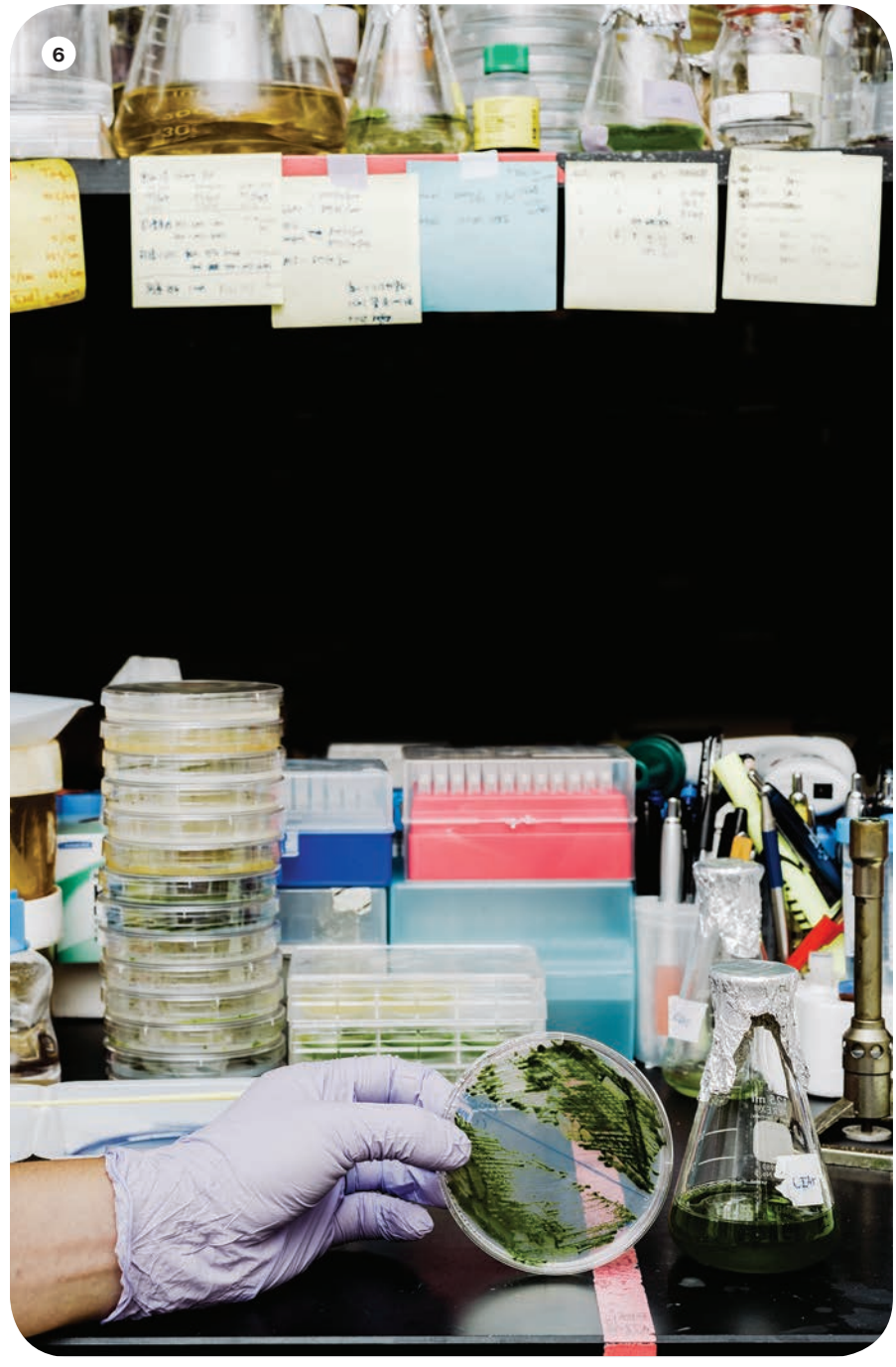
1 This robot maneuvers itself through fields to measure biomass and other aspects of plant growth.

2 These young cassava plants have been genetically engineered to process sunlight more efficiently.

3 The engineered tobacco plants in this greenhouse are paired with bags to collect the seeds they drop, for use in future tests.







4 This apparatus, clamped onto a tobacco leaf, probes the plant's metabolism. It measures temperature and humidity at the leaf's surface and siphons oxygen and other gases emitted by the leaf into a chemical analyzer.

5 A map of chlorophyll in a plant, made by a fluorescence imager.

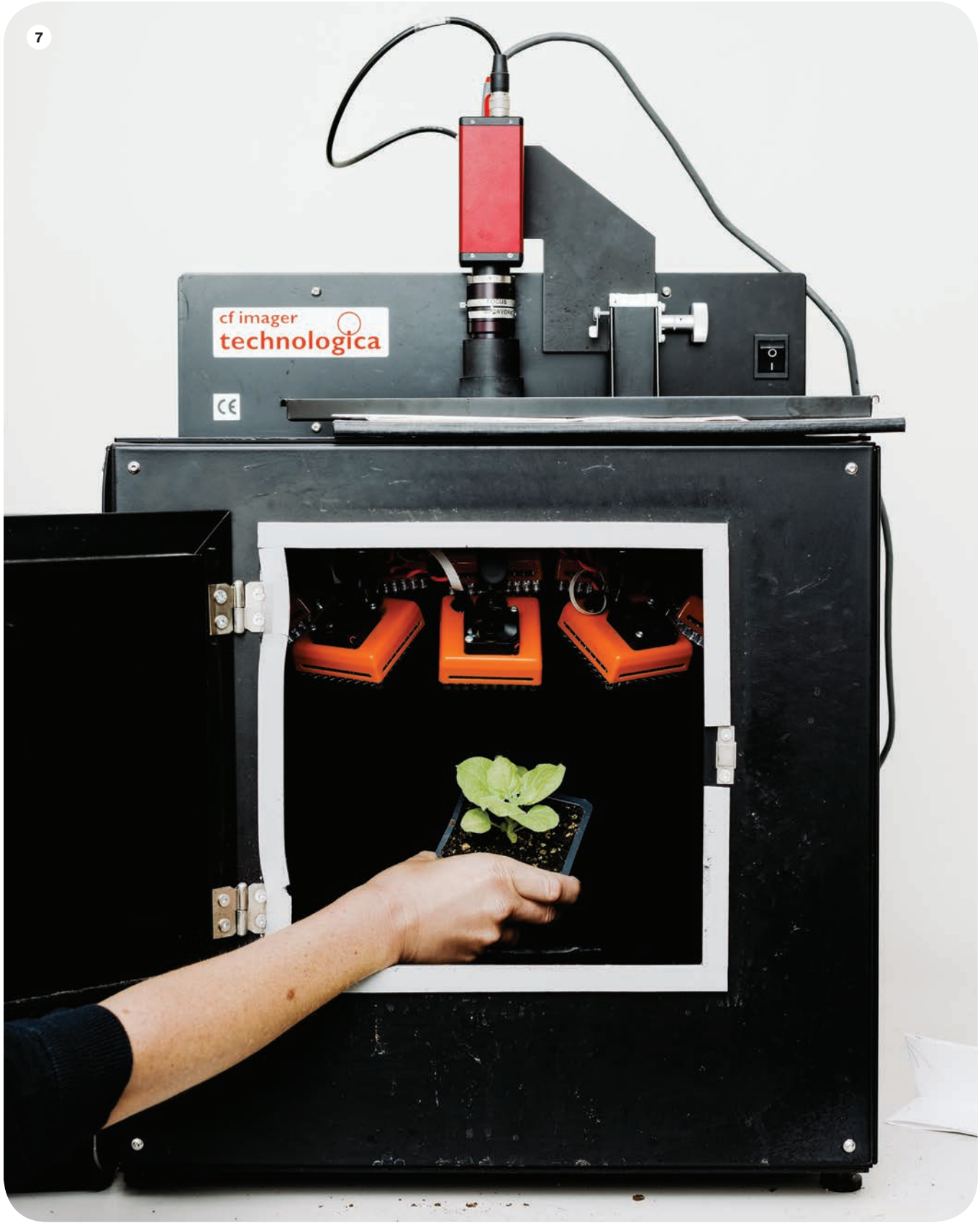
6 Some of the basic research on the molecular biology of photosynthesis is done in algae in petri dishes.

7 A fluorescence imager exposes plants to flashes of bright light to measure how quickly they respond to changing light levels.

changes to plant metabolism than have been made before.

Agronomists have not yet pushed photosynthesis to its limits. That's in spite of the fact that this 160-step biochemical process is very well studied, and surprisingly inefficient—plants convert less than 5 percent of the energy in sunlight into biomass. A still smaller part of that is invested in the parts of plants people like to eat: seeds, tubers, beans. Modern agriculture has improved yields tremendously thanks to fertilizers, pesticides, and traditional breeding. Now gains are harder to come by. That's why the RIPE group is targeting inefficiencies in plant metabolism. (Other researchers are trying variations on the same idea; see "10 Breakthrough Technologies 2015: Supercharged Photosynthesis.")

Last year, RIPE researchers demonstrated for the first time that it was possible to improve crop yields in the field by engineering photosynthesis. By increasing the expression levels of three genes involved in processing light, they improved tobacco yields by 20 percent.


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8

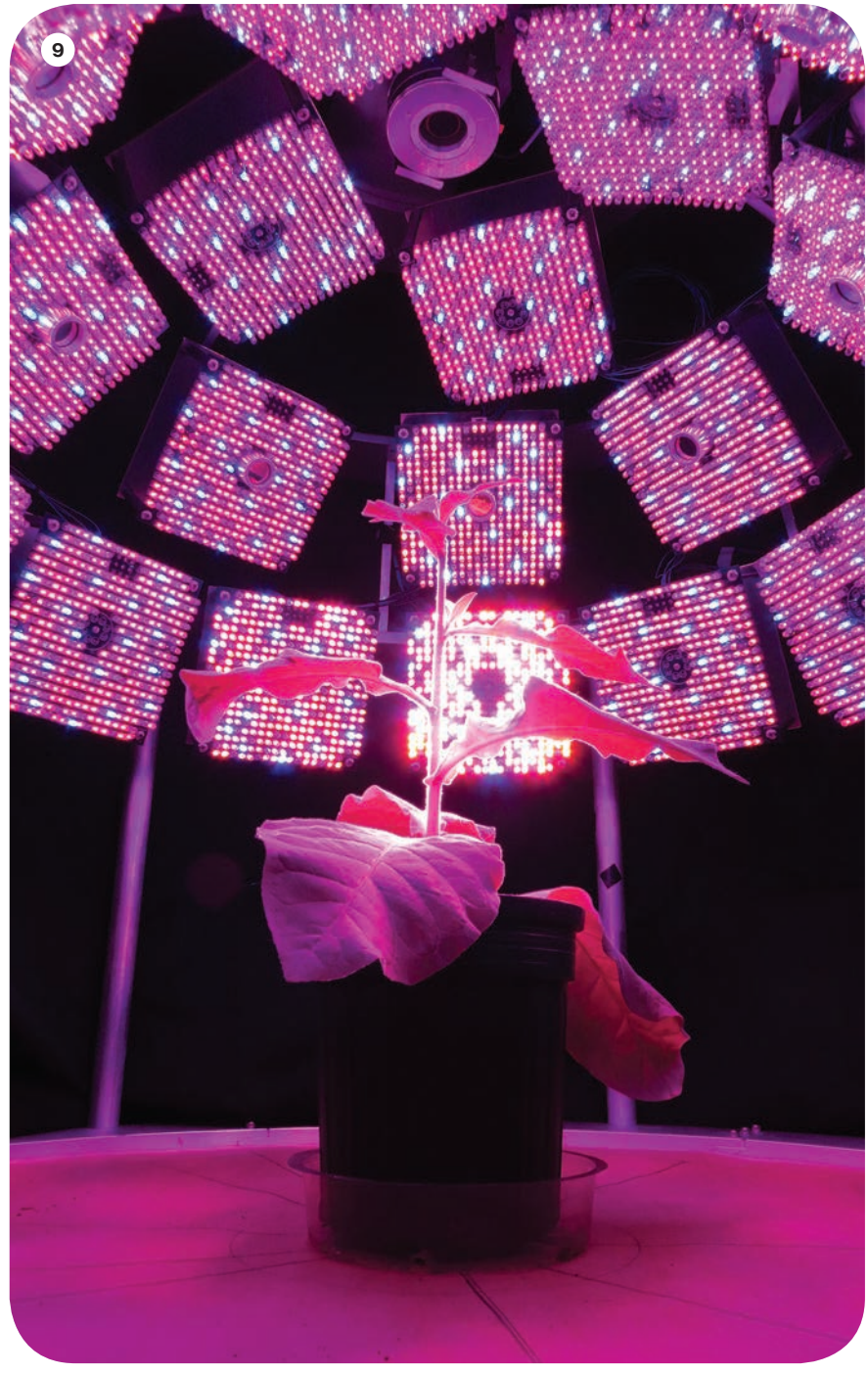
Now the RIPE team is trying to use the same genetic-engineering trick to increase yields in more recalcitrant food crops. Making it happen in cassava falls in part to Amanda De Souza, a postdoc from Brazil.

Genetic engineering of photosynthesis in cassava is a delicate and lengthy process. De Souza opens a petri dish to show off cassava embryos, light-yellow clusters about a millimeter wide. She grows them using tissue plucked from a bud on a full-grown cassava plant. This cluster of cells, called a "callus," can be infected with bacteria carrying the light-processing genes. Only a few cells will actually take up the genes. Those that do will then be exposed to a hormone cocktail that will drive them to grow a stem and roots.

In cassava, this genetic transformation takes eight to 10 months—that is, if everything goes well. Other key food crops, including rice and cowpeas, are a bit faster.

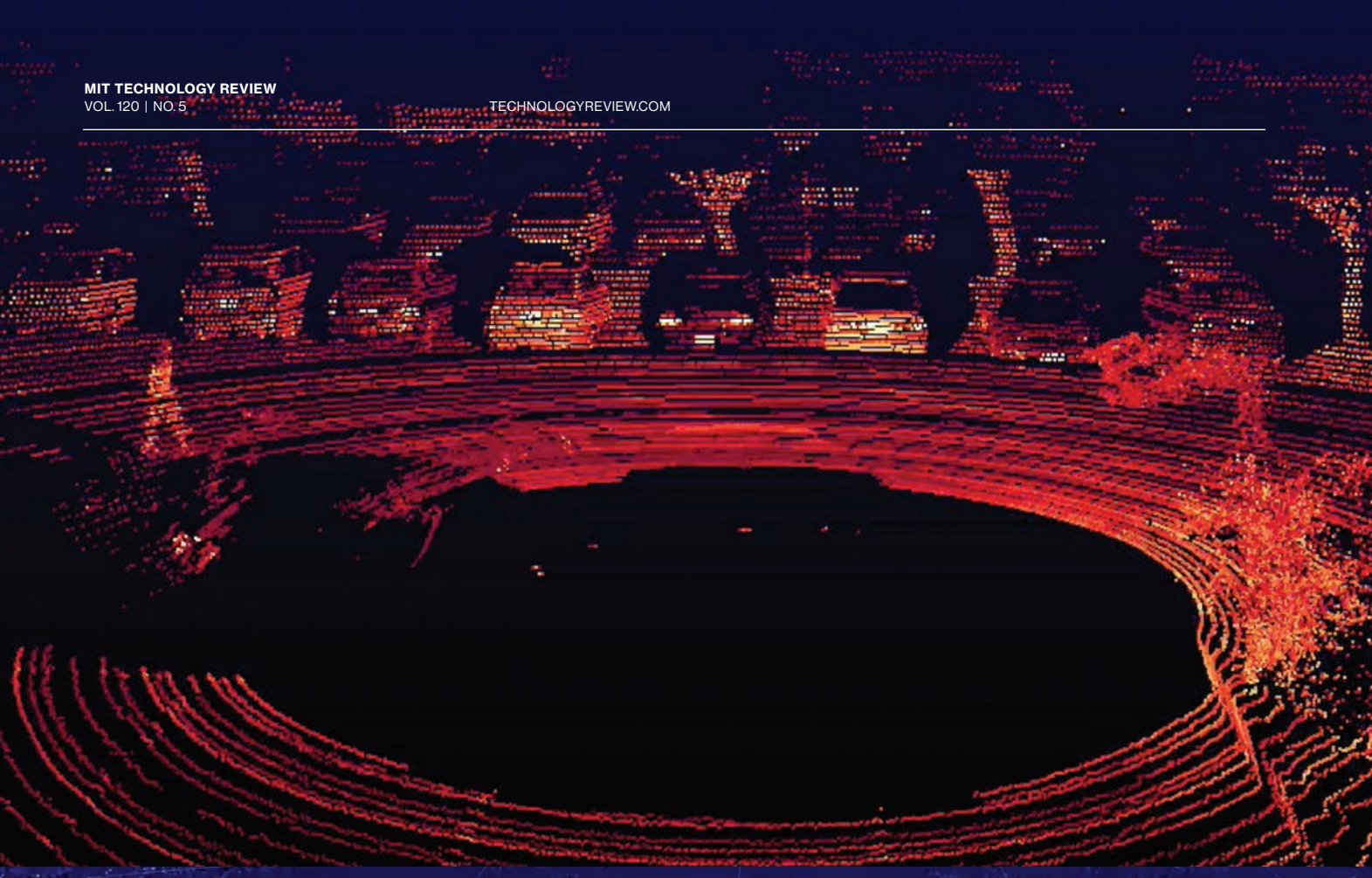
Down the hall, De Souza opens a closet-like room flooded with artificial sunlight. On shelves, young cassava plants are growing in plastic jars, their roots surrounded by a nutrient gel that will be picked off by hand before the plants can go into the soil.

RIPE's experimental fields are a 10-minute drive from the labs. In this part of the country, farms mostly grow soybeans and corn. It falls to David Drag, RIPE's field trials manager, to figure out how central Illinois's soil can nurture crops like cassava and rice. For one project a collaborator helped him build a rice paddy. But in 2015, he recalls ruefully, he saw one of RIPE's key projects drown in a severe late-season rainstorm, in spite of the team's efforts to dig trenches and dams. A year's work was lost—a humbling reminder that even the most advanced agricultural science is still at the mercy of nature.



KATZYNA GLOWACKA (9)

8-9 A view inside the fluorescence imager. These experiments have helped to establish that tobacco plants produce higher yields if they can more quickly turn off production of a "molecular sunscreen" when light levels drop. Plants that perform well in these experiments go on to field trials.



Laser Vision

Most autonomous vehicles use laser sensors, or lidar, to map the world in 3-D, but the hardware varies in quality. Here are two images from sensors made by market leader Velodyne: the top view is from an $80,000 sensor, while the device that made the bottom image costs $8,000. More detail makes for safer driving. —*Jamie Condliffe*

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